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THE
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VOLUME XXXIX APRIL 1914 NUMBER 3

THE COMPLEX STRUCTURE OF SPECTRUM LINES

By CH. WALI-MOHAMMAD

The following investigation was carried out under the kind supervision of Professor W. Voigt in the physical laboratory of the Göttingen University. It represents the checking and the extending of the results published by Dr. L. Janicki.[1] The object was the comparison of the results obtained by Dr. Janicki by means of crossed parallel interference-plates with those yielded by an echelon grating of very high resolving power.

A. SOURCE OF LIGHT

Introduction.—In 1892 A. A. Michelson showed that some of the spectral lines are not simple but possess a complex structure. Since 1892 several spectroscopic instruments of very high resolving power (e.g., interferometer, echelon grating, parallel interference-plates, etalon, etc.) have been constructed and the structure of several lines investigated. But so far no satisfactory source of light, which could be used with the above instruments, has been found. (1) Flames are obviously useless for this purpose. (2) Spark spectra have yielded practically no results worth mentioning. (3) Geissler tubes, which are so useful in the cases of gases, have a very limited application and cannot be successfully

[1] *Annalen der Physik*, **29**, 833, 1909.

used in the case of metals. (4) Arc spectra are the only ones that have yielded any results, and these must be excited in a vacuum. Here may be mentioned the amalgam-lamps of different makes, but the number of substances that can be used with them is extremely limited.

A. Wehnelt[1] discovered the properties of his oxy-cathode in 1904 and Wehnelt and Wiedemann[2] showed later on how the oxy-cathode could be used in conjunction with an anode of a given metal to melt and vaporize the anode and thus produce an arc in vacuum.

Janicki (*loc. cit.*) took up the subject and constructed a discharge tube which gave very satisfactory results. The writer modified the form and size of Janicki's tube in such a way as to enable it to be placed in a magnetic field and thus to observe the Zeeman effect not only on the principal lines but on the satellites which accompany some of the principal lines, as well.

The oxy-cathode possesses the following advantages: (1) The source of light is an arc in vacuum—an absolute condition for producing very sharp lines. (2) The spectrum is pure in the sense that neither the carbon bands nor the air lines are present. (3) The lines are extremely *sharp* and most suitable for use with instruments of very high resolving powers. (4) The lines are intensely bright and consequently require very short exposure. (5) Nearly all metals can be used with the necessary alterations. (6) The rate of vaporization of the metal is under control and can be regulated as desired. (7) The temperature arrived at is very high and the spectrum extends farther into the violet than is the case with other sources of light.[3] (8) The source of light is capable of being placed in the magnetic field, and thus the Zeeman effect on the satellites can be easily observed.

Discharge tube (Fig. 1).—The discharge tube AB is of Jena glass 30 cm long and 30 mm in cross-section. The upper end is closed by means of a glass plate P and through this the light passes out to the spectroscope. The lower end is attached by means of

[1] *Op. cit.*, **14**, 425, 1904.

[2] *Physikalische Zeitschrift*, **6**, 690, 1905.

[3] Wehnelt and Wiedemann, *loc. cit.*

sealing wax to a small tube BC, through the ground end C of which passes the tube T carrying the cathode and the anode. $A'A'B'B'$ is the cooling mantle through which a constant flow of water takes place.

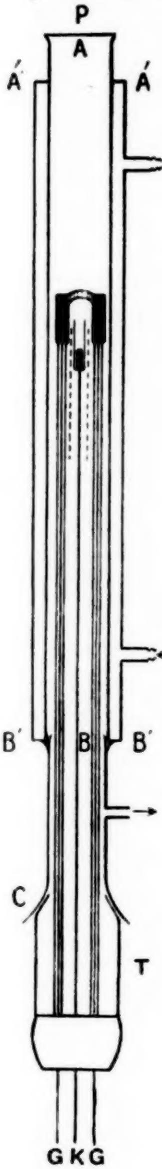

FIG. 1

Cathode (Fig. 2).—The cathode consists of platinum foil 0.015 mm thick and 30 mm long held in a semicircular form between two thick brass pieces DE and DE. The breadth of the cathode varies between 4 and 6 mm according to the current flowing between the cathode and the anode. The platinum foil is dipped in a solution of calcium nitrate and barium nitrate and heated in order to reduce the salts to their oxides. The cathode was then heated by means of a current from an accumulator battery (40 volts); the heating current was usually about 15 or 16 amperes.

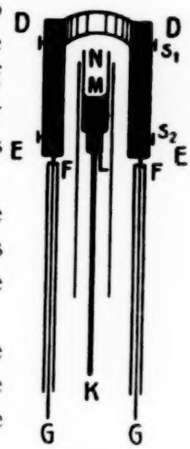

FIG. 2

It may be remarked here that the cathode has a very short life—it gets burned through after it has been in use for some time.

Anode.—The anode consists of the given metal placed in a porcelain tube NM and is in electrical contact with the brass piece ML and the wire LK.

Pressure.—The necessary vacuum was produced by means of Dr. Gaede's rotary pump. The pressure was generally less than 0.01 mm Hg.

Current.—A potential difference of 220 volts was set up between the anode and the red-hot cathode. When the vacuum had arrived at the proper value an arc was set up between the cathode and the anode and a current passed between them. By means of suitable water-cooled resistances this current could be regulated easily and controlled. Different metals require different current-strengths in order to set up the arc and to vaporize them properly. According

to Wehnelt the passage of 3 amperes produces the heat-equivalent of 60 to 90 watts at the anode and suffices to melt and to vaporize most of the metals. Evidently the amount of current necessary depends on the specific heat and the melting-point of the given metal. The current varied from 0.02 to 0.6 ampere (for zinc, cadmium, etc.) to 3 to 5 amperes (for cobalt, chromium, etc.).

B. INSTRUMENTS OF OBSERVATION

Spectroscope.—An echelon grating constructed by A. Hilger of London was used in conjunction with a monochromator. The echelon consists of 35 plates. Each plate is 9.945 mm thick and the breadth of the step is 1 mm. Its resolving power lies between 285,000 and 665,000 for the Fraunhofer lines A and H respectively and the limit of the wave-length difference ($d\lambda$) capable of being resolved is 0.027 and 0.006 A respectively.

Method of observation.—All the lines under discussion were photographed and measured by means of a Zeiss microscope. For photographing the lines, plates of various makes were used. I employed Lumière's plates for the blue and violet, Viridin plates of Dr. Schleussner (Frankfurt) for the green and yellow, and Pinacyanol bathed and Panchromatic plates of Wratten & Wainwright (London) for the red end of the spectrum.

As already mentioned, the source of light is extremely bright and the time for photographing a line comparatively short. The following table shows the advantage of an oxy-cathode over other sources of light:

BISMUTH LINE $\lambda=4722$

Observer	Source of Light	Observing Instrument	Exp.
(1) Lunelund.............	Quartz amalgam-lamp	Echelon	$1\frac{1}{2}$ to $2\frac{1}{2}$ hrs.
(2) Gehrcke and von Baeyer	Amalgam-lamp	Parallel plates	$4\frac{1}{4}$ hrs.
(3) Author...............	Oxy-cathode	Echelon	$\frac{1}{2}$ min.

C. RESULTS

1. ALUMINIUM

Current, 1 to 2 amperes Melting-point, 66° C.

The only lines in the visible spectrum are λ 3961.7 and λ 3944.2. Both these lines are bright, sharp, and simple. With

a current of 2 amperes they show reversal. In addition to these two lines there are three strong bands in the blue which all shade down toward the red end of the spectrum.

2. ANTIMONY

Current, 0.5 to 4.5 amperes — Melting-point, 625° C.

It is remarkable that antimony in spite of great evaporation gives no line spectrum. Only a band spectrum rich in lines is to be seen. An increase in the current fails to bring out any lines that are strong enough for observation.

An alloy of antimony with lead and zinc was also employed but without any better results.

3. BISMUTH

Current, 0.5 to 4 amperes — Melting-point, 268° C.

The intensely blue line λ 4722 is the first to appear with a current of about 0.5 ampere. With a greater current very few more lines appear. With 4 amperes the lines λ 5552.4, λ 4733.9, and λ 4561.3 are seen and all of them are simple. A band in the green also becomes visible and shades down toward the red end of the spectrum.

The structure of a few bismuth lines has been investigated by von Baeyer[1] alone and by von Baeyer and Gehrcke.[2] They used a quartz bismuth amalgam-lamp of their own construction. Lunelund[3] also investigated the bismuth lines by means of Arons'[3] amalgam-lamp.

$\lambda = 4722$ (Blue)

$\lambda = 4722$ $d\lambda_{max} = 0.345$ A Exposure, ½ minute

Crossed Interference-Plates			Echelon Grating			
Gehrcke and von Baeyer		von Baeyer	Lunelund		Author	
			0.166?	1		
			−0.144?	1	−0.144?	1
+0.242(= −0.103)*	2	+0.242(= −0.103)	−0.105?	4	−0.103	3
+0.289(= −0.056)	1	+0.283(= −0.062)	−0.062	3	−0.061	5
+0.316(= −0.029)	1	+0.318(= −0.027)	−0.031	3	−0.029	7
0.000	....	0.000	0.000	10	0.000	10
+0.057	1	+0.058	+0.059	5	+0.057	8
+0.104	3	+0.100	+0.103	2	+0.102	6

* The numbers within the parentheses have been introduced by the author.

[1] *Verh. deutsch. phys. Gesells.*, 1907.

[2] *Annalen der Physik*, **20**, 285, 1906.

[3] H. Lunelund, Inaug. Diss., Helsingfors, 1910; *Annalen der Physik*, **34**, 505, 1911.

Since $d\lambda_{max}=0.345$ A, the values given by Gehrcke and von Baeyer represent the values given within the parentheses (obtained by subtracting from 0.345 the values given by them). In this way the agreement between the results of different observers becomes apparent. Nevertheless the position of the first three satellites is not established beyond doubt.

It may be mentioned here that the formulae for the dispersion of an echelon grating show that there may exist an ambiguity in the results deduced from them. It is sometimes very difficult to say to which principal line a particular satellite belongs. Recently P. Gmelin[1] has suggested a method for removing such ambiguity, but I had no time for availing myself of his method.

Gehrcke and von Baeyer, too, are not sure of their having correctly arranged the satellites of this line. The evidence of Michelson's plane grating, which has already helped in giving the correct order of the satellites of mercury lines, may also throw some light here.

$\lambda=4122$ (Violet)

According to Gehrcke and von Baeyer, this line is composed of three components of nearly the same intensity and they arbitrarily consider the middle component to be the principal line.

Lunelund had to expose his plate for fully five hours in order to photograph it, and he found that it consists of four components. The figures are:

Gehrcke and von Baeyer	....	−0.21	0.00	+0.15
Lunelund	−0.11	−0.05	0.00	+0.05

The wave-lengths of the line given by Gehrcke and von Baeyer and Lunelund are 412 $\mu\mu$ and 4122 A respectively.

I find that the line is not complex at all. The measurements of the wave-lengths of the line under observation show that there are two distinct lines separated from one another by a distance equal to about $\frac{1}{3}$ or $\frac{1}{4}$ A. The lines given are, according to

Kayser and Runge[2]	4122.01	Diff. = 0.32 A
(Arc)	4121.69	
Exner and Haschek[3]	4122.10	Diff. = 0.24
(Arc)	4121.86	
Exner and Haschek[3]	4122.08	Diff. = 0.33
(Spark)	4121.75	

[1] *Annalen der Physik*, **33**, 17, 1910.

[2] *Abhandlungen Berliner Akad.*, 1893.

[3] *Tabellen der Spektra*, Wien, 1902.

It appears that the above mentioned observers (Gehrcke and von Baeyer and Lunelund) have not distinguished the foregoing two lines from each other. Perhaps Gehrcke and von Baeyer observed a "ghost," since they could not use the crossed interference-plates owing to the faintness of the lines, and had to photograph them by means of a single interference-plate. Gehrcke and von Baeyer required an exposure of 8 hours while Lunelund required one of 5 hours. I exposed my plate for only 5 minutes and got a photograph showing two equally bright and sharp lines which appeared to be two distinct principal lines and not satellites. I believe that λ 4122 is not one line but two simple lines situated near each other.

4. CADMIUM

Current, 0.25 to 0.6 ampere Melting-point, 325° C.

Cadmium is an easy metal to employ and the lamp burned very smoothly and for a long time.

The following three lines possess satellites:

λ	Half-Silvered Air Plates	Crossed Interference-Plates			Echelon Grating						
	Fabry* and Perot	Gehrcke† and v. Baeyer	Janicki‡		Janicki ||		Lunelund ¶		Author		Exp.
5086.1 (ss)	+0.076 0.000 −0.024	+0.081 0.000	+0.77 0.000	2 1 ..	+0.076 0.000 −0.026?	$\frac{1}{5}$ 1 $\frac{1}{8}$	+0.078 0.000	2 10 ..	+0.076 0.000 −0.026	2 10 1	3 min.
4800.1 (ss)	+0.082 0.000 0.000 −0.082	+0.063 0.000 −0.038 −0.083	+0.058 0.000 −0.034 −0.081	2 1 3 4	+0.059 0.000 −0.034 −0.080	$\frac{1}{4}$ 1 $\frac{1}{6}$ $\frac{1}{5}$	+0.060 0.000 −0.034 −0.080	2 10 3 2	+0.058 0.000 −0.034 −0.081	6 10 3 6	3 min.
4678.4 (s)	....	+0.035 0.000 −0.055	+0.030$_3$ 0.000 −0.055$_8$	2 1 3	+0.030 0.000 −0.056	$\frac{1}{3}$ 1 $\frac{1}{6}$	+0.032 0.000 −0.056	3 10 3	+0.031 0.000 −0.056	3 10 6	$1\frac{1}{2}$ min.

(s) = bright (ss) = very bright.

* Ch. Fabry, *Comptes rendus*, **138**, 854, 1904.

† *Annalen der Physik*, **20**, 269, 1906.

‡ *Ibid.*, **29**, 833, 1909.

|| *Ibid.*, **19**, 36, 1906.

¶ *Loc. cit.*

λ 5086.—It is remarkable that Janicki with his echelon grating finds a satellite at −0.026 but with his parallel-plates fails to observe it. Hamy and Fabry, too, have observed this satellite. Lunelund using an Arons' amalgam-lamp and an echelon and giving an exposure of about one hour could not find this satellite. The

probable reason why Janicki failed to observe it with the parallel-plates is the following:

The principal line is very broad and bright, while the satellite is very fine and faint. The latter is visible with a current of 0.2 or 0.3 ampere; with a greater current than this, it merges into the principal line. On account of the irradiation it is not possible to photograph the satellite as a separate line when an ordinary photographic plate is used. Hence the need of a "non-halation" plate for such cases. In this way I measured the distance of the satellite from the principal line and found it in close agreement with the measurements of Hamy, Fabry, and Janicki.

The following lines are sharp and simple:

6439.3 (ss)	5154.9	4662.7

5. CHROMIUM

Current, 1 to 4 amperes — Melting-point, 1515° C.

The vaporization was very irregular and the emitted light sometimes deepened in color suddenly and many new lines became visible. The spectrum is very rich in lines which lie so near each other that their identification becomes somewhat difficult.

The following lines, in agreement with Janicki, were found to be simple:

5410.0 (s)	4871.0	4565.7
5348.5	4862.0	4546.1 (ss)
5346.0 (s)	4829.5	4544.8
5329.3	4789.5	4540.9
5328.5 (s)	4756.3	4540.7
5298.4	4718.6	4535.9
5296.9	4708.2	4530.9
5276.2	4652.3 (s)	4526.6
5275.9	4651.4 (s)	4497.0 (s)
5275.3	4646.3 (s)	4385.1 (s)
5265.9	4626.3 (s)	4371.4 (s)
5264.3	4616.3 (s)	4359.8
5247.4	4613.5 (s)	4351.9 (ss)
5208.6 (ss)	4600.9	4351.2
5206.2 (ss)	4591.6	4344.7 (s)
5204.7 (ss)	4580.2	4339.8
4922.4	4569.8	4339.6

The three bright lines λ 4289.9, λ 4274.9, and λ 4245.5 show a peculiar behavior. Each of these lines appears to be accompanied

by a so-called "variable satellite," i.e., a satellite of which the distance from the principal line depends on the current-strength. My observations agree with those of Janicki and can be summed up as follows: (1) With a very small evaporation from the anode (i.e., with about 0.7 ampere), the lines are simple. (2) With an increase in the current, the lines become double. (3) The intensities of the components are different, being for the three lines above in the ratio of 1:6, 1:5, and 1:6 respectively. (4) With an increase in the current, the distance between the two components increases. (5) This increase in the distance is, as a rule, only possible when the current-strength is increased from low to high values. When the current is decreased from high to low values, the change in the distance does not occur with the same rapidity.

It appears from the foregoing, that here we have a case of unsymmetrical reversal. W. Hartmann[1] has observed these same lines in a magnetic field and he finds that their intensity increases considerably in the magnetic field. He also found that they show strong reversal and that the distance of the components varies, each component giving rise to a triplet.

In the case of magnesium,[2] where there is not the slightest doubt that the lines show reversal, we find a similar behavior—the only difference being that in this case the reversal is quite symmetrical.

For the line λ 4289.9, the distances between the two components were:

0.7 ampere	0.000 (simple)
2.0	0.017 A
2.5	0.020 A
3.0	0.024 A

The other two lines behave in exactly the same manner.

6. COBALT

Current, 3 to 5.5 amperes Melting-point, 1500° C.

The spectrum is very rich in lines and requires a very high current to produce them. Janicki finds that the four lines in the blue possess satellites. I find that only one of them has a real satellite while the other three are most probably cases of reversal

[1] Dissertation, Halle, 1907. [2] See p. 197.

which arise from the high currents used. It may be mentioned in passing that with such intense currents the porcelain tube containing the anode melts easily.

The following lines, in agreement with Janicki, were found to be simple:

5483.6	5342.9 (s)	4780.0
5444.8	5280.8	4749.9
5369.8	5266.7	4663.6
5369.1	4860.0 (s)	4531.1 (s)
5353.7	4840.4 (s)	4121.5 (ss)
5352.2 (s)	4813.7 (s)	4118.9 (s)
5343.6	4793.0	4110.7
		4092.6 (s)

The following lines were not simple:

λ	Janicki	Author
4629.5	+0.044 (2) 0.000 (1)	+0.045 (3) 0.000 (10)
4581.8	+0.065 (1) 0.000 (1)	Simple (reversal)
4565.7	+0.058 (1) 0.000 (1)	Simple (reversal)
4549.8	+0.048 (1) 0.000 (1)	Simple (reversal)

Janicki remarks that each of the last three lines consists of two equally bright components with a great resemblance to reversal. He found that by increasing the strength, the increase in the distance between the two components could not be noticed.

On the other hand, I found that with a current of about 4 amperes the lines were simple, and with an increase in the current, they became double, both the components being equally bright. It appears that Janicki had chosen a current of 5 or 6 amperes to start with and had consequently found the lines to be double.

7. COPPER

Current, 2 to 3.5 amperes — Melting-point, 1080° C.

Copper is not an easy metal to use, as in the molten metal a gas bubble is formed which acts as an insulator between the

metal above and the metal below. To avoid this difficulty an alloy of silver and copper (80 per cent silver) was employed which vaporized quite satisfactorily. The color of the light was rich bluish-green.

The following lines, in agreement with Janicki, were found to be simple:

5220.2	I N I 4	4507.8 (s)	
5218.4 (ss)	I N I 4	4480.5 (s)	II N II 4
5153.4	I N II 4	4063.5	I N I 5
5105.8 (s)		4062.9 (ss)	I N I 5
4651.3 (s)		4022.9 (ss)	I N II 5
4531.0 (s)	II N I 4		

The following lines possess satellites:

λ	Janicki		Author		Exp.
5782.3 (ss)	0.000 −0.058 −0.096	1 2 2	0.000 −0.057 −0.095	10 5 5	6 min.
5700.4 (s)	0.000 −0.054 −0.086	1 2 2	0.000 −0.054 −0.090	10 5 5	6 min.
4704.8	+0.072 +0.033 0.000	2 2 1	+0.073 +0.034 0.000	6 6 10	4 min.
4275.3	+0.048 0.000	2 1	+0.048 0.000	4 10	5 min.

The two yellow lines λ 5782 and λ 5700 possess similar structure. From my measurements the components of the latter can be found from those of the first by multiplying it by $\frac{18}{19}$.

The separation of these satellites is rather small and they are probably due to the reversal of only one satellite. Nevertheless, an increase in the current does not seem to affect their distance apart, hence I believe that they are real satellites.

The evidence against this view is that Hartmann (*loc. cit.*) observed that the lines λ 5782 and λ 5700 are double lines and that their distance apart is 0.080 and 0.082 A respectively. Further, the Zeeman effect of these lines as observed by Michelson and by Hartmann shows some peculiarities. Under the influence of the

magnetic field, the components approach each other and give rise to a single narrow line without any broadening. Then they separate from one another, leaving behind a middle line.

8. LEAD

Current, 0.05 to 2.0 amperes Melting-point, 327° C.

Lead alone and an alloy of lead and tin were used. It was found that the alloy burned much more smoothly than the lead alone. Janicki found that on the surface of lead used at the anode a layer of oxide was formed very quickly and consequently he had to take special precautions to avoid this difficulty. The alloy presents no such difficulties.

The following lines, in agreement with Janicki, were found to be simple:

6041.2	5005.6 (s)
6002.1	4387.3 (s)
5875.0	4168.2 (s)
5547.2 (s)	4062.3
5045.9	4019.7 (s)

The following lines possess satellites:

λ	Janicki		Author		Exp.
6657.3 (s) F	0.000 −0.136	1 2	0.000 −0.130	10 3	6 min.
5608.2 (s) F	0.000 −0.085	1 2	0.000 −0.085	10 3	5 min.
5373.6 F	$+0.166_3$ $+0.079_4$ 0.000 -0.111_9	3 2 1 4	$+0.166_2$ $+0.077_4$ 0.000 -0.111_6	4 4 10 3	6 min.
5201.6	simple	....	+0.063 0.000	2 10	6 min.
4545.2 F	$+0.077_5$ $+0.037_0$ 0.000 -0.051_7	3 2 1 4	$+0.077_2$ $+0.036_0$ 0.000 -0.052_0	4 4 10 3	6 min.
4058.0 (ss)	+0.033 0.000 −0.041	2 1 3	+0.032 0.000 −0.041	5 10 5	5 min.

s = bright ss = very bright

Janicki has pointed out the similar structure of the lines λ 5373 and λ 4245 and shows that the satellites of the latter can be deduced from those of the former by multiplying them by 0.465.

9. MAGNESIUM

Current, 0.2 to 1.0 amperes Melting-point, 630° C.

Magnesium powder was used and the lamp burned quite smoothly. The color of the light is intensely green.

The following lines, in agreement with Janicki, were found to be simple:

5711.6		4571.3 (s)	
5528.7 (s)		4352.2 (s)	
5183.8 (ss)	reversal	4167.8	
5172.9 (ss)	reversal	3838.4 (ss)	reversal
5167.6 (ss)	reversal	3832.5 (ss)	reversal
4703.3 (s)		3829.5 (ss)	reversal

The lines forming the triplet in the green and the triplet in the ultra-violet show an easy reversal and it is consequently difficult to get them as simple lines. In this case was applied for the first time the sure test of the difference between a line showing reversal and a line possessing a satellite. Apparently the two cases are very similar. With an extremely small vaporization of the metal, i.e., with a current of 0.2 ampere, the lines were found to be simple. As the vapor-density was increased by increasing the current, the line divided into two equally bright components whose distance from each other increased with the increase in the current.

The measurements made on the line λ 5167.8 gave the following results:

Current	Distance between the Components
0.2 ampere	0.000 A (simple)
0.4	0.028
0.6	0.049
0.8	0.055

The components are equally bright and are symmetrically situated with respect to the original line. The lines λ 5183 and λ 5172 show similar behavior.

P. G. Nutting[1] has investigated the structure of the magnesium lines. Using an arc for his source of light, he found all the lines to

[1] *Astrophysical Journal*, **23**, 64, 1906; **24**, 111, 1906.

be simple. With greater currents he found each of the three green lines to be double. Evidently this was a case of reversal regarded by Nutting as a change in the structure of the lines.

10. MANGANESE

Current, 0.7 to 2.0 amperes Melting-point, 1245° C.

The lamp burned smoothly for a very long time with but little consumption of the metal.

The following lines, in agreement with Janicki, were found to be simple:

5255.5	4844.5	4709.9	4257.8
5196.7	4823.7 (ss)	4705.6	4239.9
5151.1	4783.6 (ss)	4502.4	4235.5 (s)
5118.1	4766.6	4499.1	4235.3 (s)
5074.8	4766.0	4491.8	4083.8
5030.8	4762.6 (s)	4490.3	4083.1
5005.1	4761.7 (s)	4436.5	4079.6
4862.3	4754.2 (ss)	4415.1	4070.4
4858.7	4739.3	4281.3	4063.4
4858.0	4727.6	4266.1	

The following lines possess satellites:

λ	Janicki		Author		Exp.
6021.8 (s)	Simple	....	Simple	....	5 min.
6016.6	Simple	....	0.000 −0.052	10 5	5 min.
6013.6	Simple	....	0.000 −0.035	10 5	5 min.
5538.1	2–3 weak satellites	....	0.000 −0.046 −0.104	10 4 3	5 min.
5517.1	0.000 −0.073 −0.118?	1 2 3	0.000 −0.070 −0.120	10 5 4	5 min.
5506.1	0.000 −0.047 −0.089	1 2 3	0.000 −0.047 −0.088	10 5 3	5 min.
5481.7	0.000 −0.065 −0.122	1 2 3	0.000 −0.062 −0.115	10 5 3	5 min.

λ	Janicki		Author		Exp.
5470.9	0.000	1	0.000	10	5 min.
	−0.056	2	−0.055	5	
	−0.105	3	−0.104	3	
5407.6 (s)	0.000	1	0.000	10	3 min.
	−0.057	2	−0.054	7	
	−0.105	3	−0.104	5	
	−1.144	4	−0.147	3	
5399.7	0.000	1	0.000	10	3 min.
	−0.055	2	−0.054	7	
	−0.102	3	−0.102	6	
	−0.143	4	−0.142	4	
5394.9	0.000	1	0.000	10	5 min.
	−0.065	2	−0.068	5	
	One more satellite		No satellite		
5388.7	....	....	0.000	10	6 min.
	....	....	−0.036	4	
	2 satellites	....	−0.066	3	
	....	....	−0.093?	3	
5377.8	0.000	1	0.000	10	6 min.
	−0.035	2	−0.037	4	
5341.2 (ss)	0.000	1	0.000	10	3 min.
	−0.057	2	−0.058	7	
	−0.108	3	−0.107	7	
	−0.149	4	−0.149	6	
	−0.183	5	−0.190	6	
4061.9	0.000	1	0.000	10	6 min.
	−0.034	2	−0.033	7	
	−0.061	3	−0.060	7	
	−0.082	4	−0.082	5	

It will be seen that all the lines show similar structure. The satellites of most lines become uniformly weaker—as they recede from the principal line and their distance from the principal line also decreases regularly—in other words, they constitute a series. Janicki found that, knowing the first satellite, the others can be calculated from the following empirical formula:

$$d\lambda_n = d\lambda_1 + \frac{d\lambda_n - 1}{1.17}.$$

Janicki found that when the current-strength was increased, the three lines λ 6021.8, λ 6016.6, and λ 6013.6 broadened and lost in sharpness *without* showing a reversal.

On the other hand, I found that the line λ 6021.8 is simple, while each of the other two possesses a satellite. The following observations show that I was not dealing with a case of reversal: (1) The three lines according to Janicki have similar structure but according to my observation they behave differently. (2) The satellite is half as intense as the principal line. (3) The distance of the satellite from the principal line does not increase with an increase in the current.

λ 5538.1.—I have measured the two satellites which Janicki could not.

λ 5394.9.—Janicki thinks that probably another satellite exists but I found no trace of any other satellites.

λ 5388.7.—Janicki found that the satellites could not be easily measured. I have measured them.

Janicki has succeeded in investigating a few more lines in the ultra-violet between λ 4040 and λ 4030. These lines lie very near each other, their wave-lengths differing from one another by a few angstroms only. Here I had three difficulties to face: (1) The prism of the accessory spectroscope employed in conjunction with the echelon grating was of dense, yellow glass and absorbed much of the violet light. (2) The dispersion of the prism was rather small and the identification of the lines so closely situated extremely difficult. (3) Lastly, the great drawback of the echelon grating was noticed here. The distance between the two neighboring orders of the spectrum became very small and the lines almost covered one another. Consequently I was not able to investigate the structure of these lines.

It may be mentioned here that Janicki, too, found difficulties with these lines. He had three different interference-plates at his disposal but he could resolve these lines with one of them only. Moreover, he had the advantage of photographing them all simultaneously.

11. SILVER

Current, 1.5 to 2.5 amperes — Melting-point, 960° C.

Pure silver and an alloy of silver and copper were used. The lamp burned for a very long time with a very minute consumption of the metal. The color of the light was intense green.

The following lines, in agreement with Janicki, were found to be sharp and simple:

5471.7 (s)	I N I 4	4212.1 (s)	I N I 5
5465.7 (ss)	I N I 4	4055.5 (s)	I N II 5
5209.2 (ss)	I N II 4	3981.9 (s)	II N I 5
4648.7 (ss)	II N I 4	3841.3 (s)	II N II 5
4476.3 (ss)	II N II 4	3810.6 (s)	I N I 6

It is worth noticing here that all the lines above belong to the first or the second subordinate series.

12. SODIUM

D Lines

There has always been more or less difficulty in getting a proper source of light for observing the D lines. A. A. Michelson[1] says that by using metallic sodium in a heated vacuum tube, the results are so variable and the character of the lines varies so much with a variation in temperature and pressure that a complete investigation is not possible. I found that in my lamp, the D lines were often visible. They arose from the porcelain tube containing the metal used as the anode. I also tried an amalgam containing a minute quantity of sodium.

With a very small current, the two D lines are simple and extremely sharp. With an increase in the current each of the two lines divides into two and the distance between the components so produced increases. The black space between these components remains perfectly sharp but the outer edges of the components become hazy. These changes are evidently due to reversal.

Like Fabry and Perot[2] and Janicki,[3] I too find that each of the D lines is simple and not composed of two components each having a very weak satellite.

13. TELLURIUM

Current, 0.02 to 0.05 ampere Melting-point, 290° C.

The lamp burned for a very long time with an extremely small consumption of the metal, one gram of the metal lasting for several hours. The light is intensely rich green and is due wholly to the green line λ 5350.6.

[1] *Phil. Mag.*, **34**, 280, 1892.

[2] *Comptes rendus*, **130**, 653, 1900.

[3] *Annalen der Physik*, **19**, 36, 1906.

Janicki found that the line λ 5350.6 has one satellite +0.1137 with an intensity equal to one-fourth of the principal line. I find the distance to be +0.114 and the intensity seven-tenths.

The principal line is much broader than any other line examined by me (cf. cadmium λ 5086) and with very small currents (less than 0.02 ampere) appears to be double. When the current is increased, the two components approach each other and give rise to a single line. Since the line appears to be double only with the smallest current available (i.e., the smallest vapor-density) it cannot be due to reversal. Although the ocular observation distinctly showed the line to be double, I did not succeed in photographing it as such.

Following are the observations made on this line:

Michelson*		Fabry and Perot†		Barnes‡		Janicki‖		Author	
0.00	1	0.000	1	0.00	1	0.000	1	0.000	10
+0.02	$\frac{1}{5}$	+0.020	$\frac{1}{2}$	0.04	$\frac{1}{4}$	....	......	Satellite	
+0.12	$\frac{1}{2}$	+0.114	$\frac{1}{2}$	0.10	$\frac{3}{4}$	0.113_7	$\frac{1}{4}$	0.114	7
+0.13	$\frac{1}{10}$	....	......	....	......	....	......	....	......

* *Loc. cit.*

† *Comptes rendus*, **126**, 407, 1898.

‡ *Astrophysical Journal*, **19**, 190, 1904.

‖ *Loc. cit.*

Michelson and Perot and Fabry used tellurium chloride in Geissler tubes.

It is interesting to note that while observing the Zeeman effect[1] on the above line, the presence and position of another satellite was indirectly determined. This satellite corresponds with +0.020.

14. TIN

Current, 2 to 3 amperes — Melting-point, 230° C.

Janicki found that when tin is used at the anode, it yields large quantities of hydrogen and that gas bubbles are formed in the molten metal which, acting as insulators, break the current and thereby extinguish the arc. He therefore took special precautions in order to overcome this difficulty. I avoided this difficulty by using an alloy of tin and lead which burned well and gave no trouble.

Tin gives only one line, λ 4524, in the visible spectrum and this line does not possess any satellite.

[1] Wali-Mohammad, *Annalen der Physik*, **39**, 247, 1912.

15. ZINC

Current, 0.3 to 0.5 ampere — Melting-point, 415° C.

Zinc was one of the easiest substances to use. The lamp burned very smoothly, and the color of the light was intense bright blue.

The following lines are sharp and simple:

6364.0 (ss)	4722.3 (ss)
5182.2	4680.4 (ss)
4810.7 (ss)	4630.1

Michelson[1] found a component of λ 4810 while Houstoun[2] found λ 4810, λ 4722, and λ 4680 to be double. There is not the least doubt that what Houstoun observed was the reversal.

It has been settled by the researches of Hamy,[3] Janicki,[4] Gehrcke and von Baeyer,[5] and Lunelund[6] that all the above zinc lines are simple and do not possess a complex structure.

CONCLUSION

It will be seen from the foregoing that of the 15 different metals investigated, comparatively very few possess complex lines. Most of the lines are simple and none of the metals shows the same abundance and complexity of satellites as mercury. Many complex lines (cf. copper, lead, manganese) possess similar structure and form a sort of minor series.

Further, some of the lines show symmetrical, while others show unsymmetrical, self-reversal. Such reversals have to be carefully differentiated from lines possessing real satellites. Complex lines should not be used as standard lines or as lines of reference.

Lastly, the results yielded by the echelon grating agree, on the whole, with those given by crossed interference-plates. The oxy-cathode proved a very useful source of light for the investigation.

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Aligarh, India

[1] *Phil. Mag.*, **34**, 280, 1892.
[2] *Ibid.*, **7**, 456, 1904.
[3] M. Hamy, Sur le spectra du zinc, *Comptes rendus*, **138**, 959, 1904.
[4] L. Janicki, *Annalen der Physik*, **19**, 36, 1906; **29**, 845, 1909.
[5] Gehrcke und O. von Baeyer, *Ibid.*, **20**, 269, 1906.
[6] H. Lunelund, Dissertation, Helsingfors, 1910.

A POLARIZATION SPECTROPHOTOMETER USING THE BRACE PRISM

By HARVEY BRACE LEMON

The two factors which chiefly control the sensibility in any form of photometer or spectrophotometer are, in the order of their importance, (1) the elimination of the dividing line between the two fields under comparison, and (2) the greatest possible conservation of light so that the illumination of the two fields shall be perhaps as large as 500 meter candles.[1] For the accomplishment of the first of these requirements there are no devices more satisfactory than the Lummer-Brodhun cube or the Brace prism,[2] both of which furnish between the two fields lines of separation of the order of a few wave-lengths only in width. For the purpose of spectrophotometry, however, the Lummer-Brodhun cube must be used with an auxiliary dispersing prism, whereas the Brace prism itself furnishes the dispersion as well as the two fields which are to be matched, and consequently excels the Lummer-Brodhun cube in fulfilling the second requirement noted above.

In working with the Brace prism for a number of years certain very serious objections to the manner of operation as proposed by Brace have been found. In the original form of this instrument changes of intensity in one of the fields are produced by changing the slit-width, and therefore the spectral purity, if a continuous spectrum is under observation. For very small changes in intensity this does not produce a noticeable difference in hue between the two fields, but for considerable variations it does, and the accuracy of the settings is thereby greatly impaired. Moreover, the intensity is proportional to the slit-width only where the spectral luminosity-curve is parallel to the axis of wave-length, unless bilateral slits are employed. When these are used the intensity is proportional to slit-width wherever the luminosity-curve is a straight line. Even this latter condition is fulfilled only

[1] Nutting, *Outlines of Applied Optics*, p. 172, 1912.

[2] D. B. Brace, "On a New System for Spectral Photometric Work," *Astrophysical Journal*, **11**, 6, 1900.

at two very limited regions of the spectrum, and consequently for general work a calibration of slit-width readings for true intensity values must be made either with a rotating-sector disk or some similar device which will give known changes of intensity in front of one source. If the value of the slit-width in front of the other source necessary to produce a match is measured and plotted against the known intensity furnished by the sector, then will the curve drawn through all such points constitute one of the curves of calibration.[1] These curves in general are not straight lines;

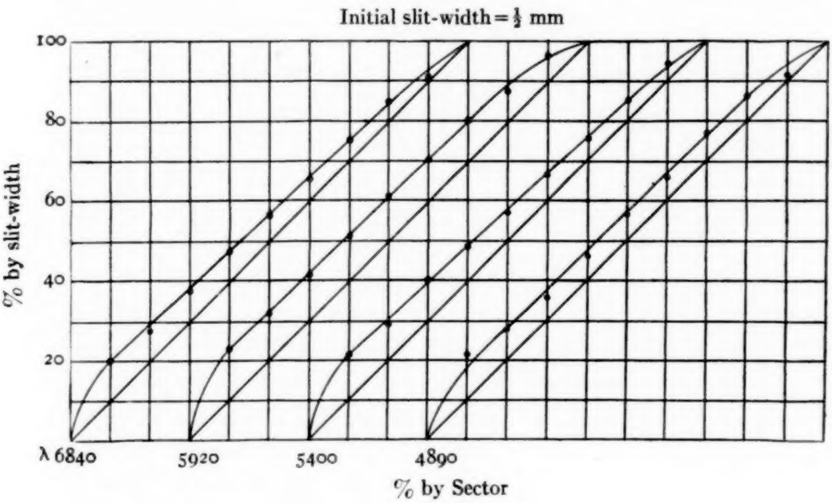


FIG. 1

they differ for every different wave-length and for every different initial value of the slit-widths. An example of them is given in Fig. 1, which shows the curves for a single initial value of slit-widths, 0.5 mm, and for four different wave-lengths. The percentage of intensity as indicated by slit-width readings is plotted against the true percentage of intensity given by the sector. If the two agree, the curve is the 45° straight line. Now a *complete* calibration consists of a double infinite set of such curves and is out of the question, of course. A calibration, to be usable for quanti-

[1] Cf. E. V. Capps, "Calibration of the Slit in Spectral Photometric Measurements," *Astrophysical Journal*, **11**, 25, 1900.

tative work, should contain observations at perhaps 10 wave-lengths for each of 5 different slit-widths, making 50 curves. The points on a single curve require about 100 individual settings. The labor involved in such a calibration is very great for the result obtained. Add to this the fact that the accidental closing of a slit too tight will change the origin of co-ordinates by an unknown amount and that any readjustment of the instrument, especially any shift of the prism, necessitates an entirely new calibration, and the great disadvantages in the use of the Brace instrument as put forth by him become apparent.

These disadvantages have been entirely overcome by the introduction into one of the collimators of the simplest sort of a polarizing arrangement. This involves no sacrifice of intensity in the other beam, which is the objection made by Brace[1] to the use of polarizing arrangements in his instrument.

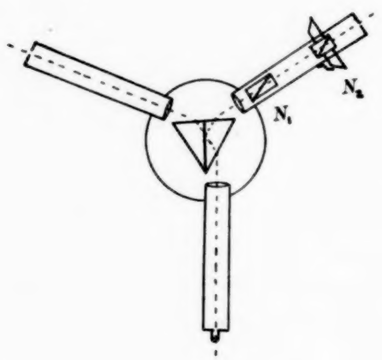


FIG. 2

The modification, Fig. 2, consists in the introduction into one of the collimator tubes of two nicol prisms, one, N_1, fixed, and the other, N_2, capable of rotation about the axis of the collimator, the amount of which is measured by a divided circle. In the mounting of these nicols three precautions must be observed:

1. The prisms must be of the form of rectangular parallelopipeds whose end faces are parallel and can be made perpendicular to the collimator axis, and an adjustment for this, especially in the case of the rotating nicol, N_2, must be provided. If the axis of rotation of N_2 is not coincident with the collimator axis, a shift of the slit-images will occur at the eye-end of the telescope which is equivalent to a shift of wave-length sufficient to make the field under observation variable in hue. With proper adjustment made by observing some brilliant spectral line such as D_3 of helium upon an ocular

[1] *Op. cit.*, p. 17.

slit or cross-hair, and adjusting the set screws provided on N_2 (not shown in the figure), the line under observation may be made to remain absolutely fixed in position while the nicol is rotated.

2. Another equally important condition is that the fixed nicol, N_1, be the nearer of the two to the Brace prism. This effects a stationary azimuth between the plane of polarization and the prism surfaces, and hence no variation in intensity can be produced by the partial polarization suffered by the light in transit through the Brace prism. Unless this precaution is taken, in fact with practically every other arrangement of the nicols in either of the collimator tubes or the telescope tube, the partial polarization of both beams produced by reflection at the glass surface of the prism and from the silver strip within is great enough to make errors in intensity amounting to 100 per cent at low intensities unless it be taken into account. The magnitude of this correction can of course be calculated from the optical constants of the instrument. It is more readily determined by a calibration similar to the one indicated above for slit-width readings. Calibration-curves of this type may consist of either a singly or doubly infinite family, depending on the location of the nicols, and consequently any arrangement of nicols other than one satisfying the condition of constancy of azimuth of the polarized beam with reference to the Brace prism can offer no improvement whatever on Brace's original form. As an example of a polarizing arrangement not satisfying the above condition of constancy of azimuth, note that given by Wallace[1] and used later by him,[2] by him and the author,[3] and by the author.[4] A calibration-curve typical of this arrangement is given in Fig. 3, where the abscissae are intensities in percentage given by the sector and the ordinates the same intensities as measured by the polarizer, i.e., given by $\sin^2 \theta$ where θ is the complement of the angle between the transmitting planes of the two nicols. The calibration-curves are seen to be functions of the wave-length. For this arrangement they are functions of the slit-widths also.

[1] "Studies in Sensitometry, I," *Astrophysical Journal*, **25**, 124, 1907.

[2] "Studies in Sensitometry, II," *ibid.*, **26**, 299, 1907.

[3] "Studies in Sensitometry, III," *ibid.*, **29**, 146, 1909.

"Spectroscopic Studies on Hydrogen," *ibid.*, **35**, 115, 1912.

For these reasons no advantage can be claimed for this arrangement over the original Brace instrument.

3. As a third condition for success the Brace prism should be so placed with reference to the collimator beams that the polarized beam is received on the silver strip as shown in Fig. 2, while the beam from the other collimator passes above and below the silver strip. All absorption due to the silver strip and the nicols is therefore put into the one beam which comes from the standard source, and losses in light can therefore be compensated for by increasing

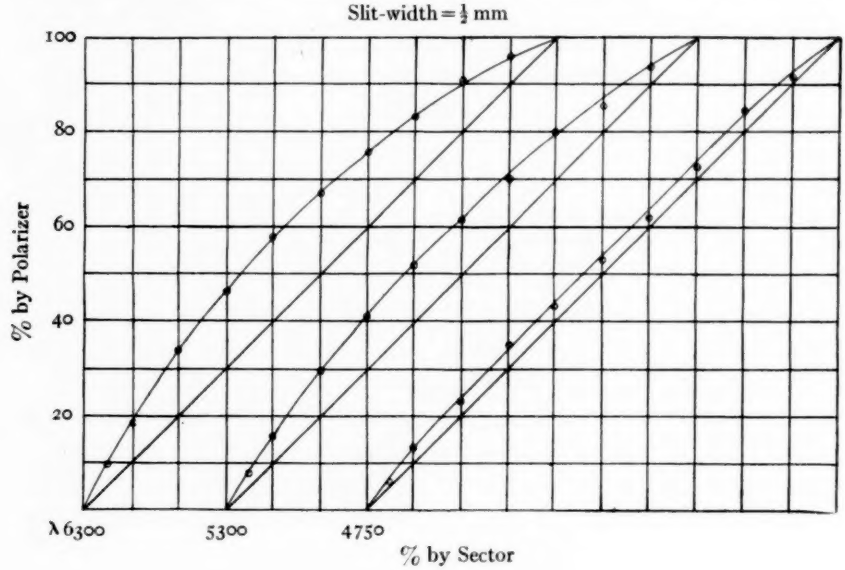


FIG. 3

the intensity of that source in which ample light is available. The other source, which is under comparison with the standard, suffers no more loss in intensity than that necessitated by the two lenses and by its dispersion through the prism. In other words, the economy of light justly claimed by Brace as being greater in his instrument than in many other forms has here in no way been sacrificed except at the standard source, where such economy is entirely unnecessary.

To determine how closely the readings from this instrument as given by $\sin^2 \theta$ conform to the actual intensities, many observations

using the rotating sector have been made. The insertion of these here in numerical detail is unnecessary since the results can be shown with great ease graphically, a single graph representing hundreds of settings. The graphs represent intensities in percentage given by $\sin^2 \theta$ plotted as ordinates against percentages given

Slit-width = $\frac{1}{4}$ mm

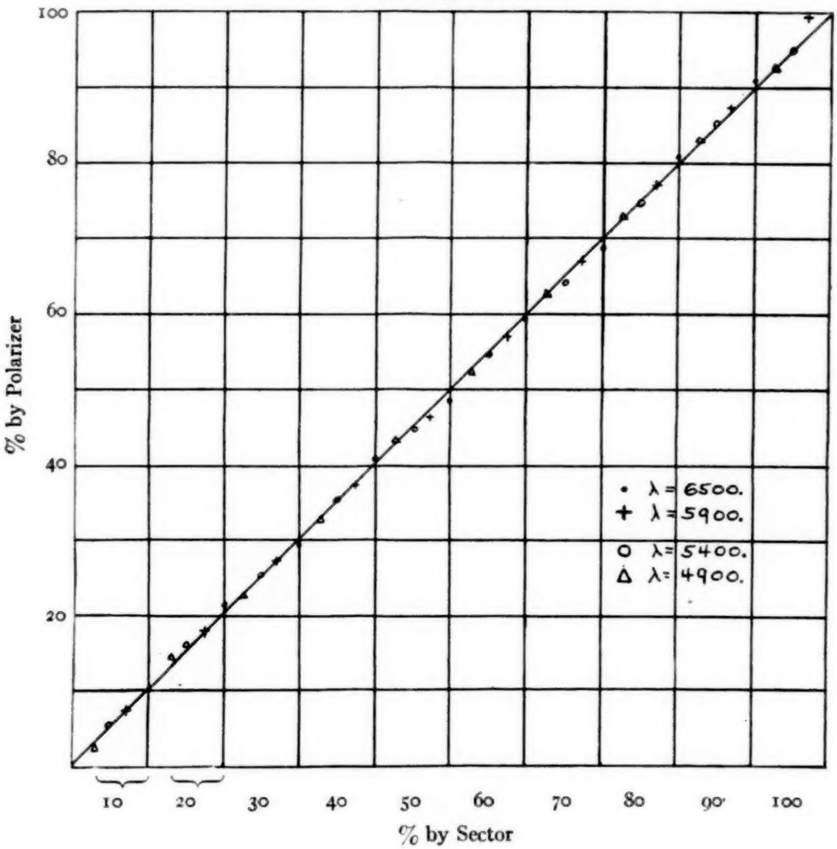


FIG. 4

by the rotating sector as abscissae. If the instrument is to be free from all necessity of having calibration-curves determined, these graphs should be coincident with the 45° straight line for every wave-length, slit-width, and condition of preliminary adjustment. Fig. 4 represents observations made at four different wave-lengths

with slit-widths of 0.25 mm. In order that points for different wave-lengths might not fall too close together, different origins have been selected, one for each color, as shown by the indicated scales of ordinates and abscissae. Thus any set of points corre-

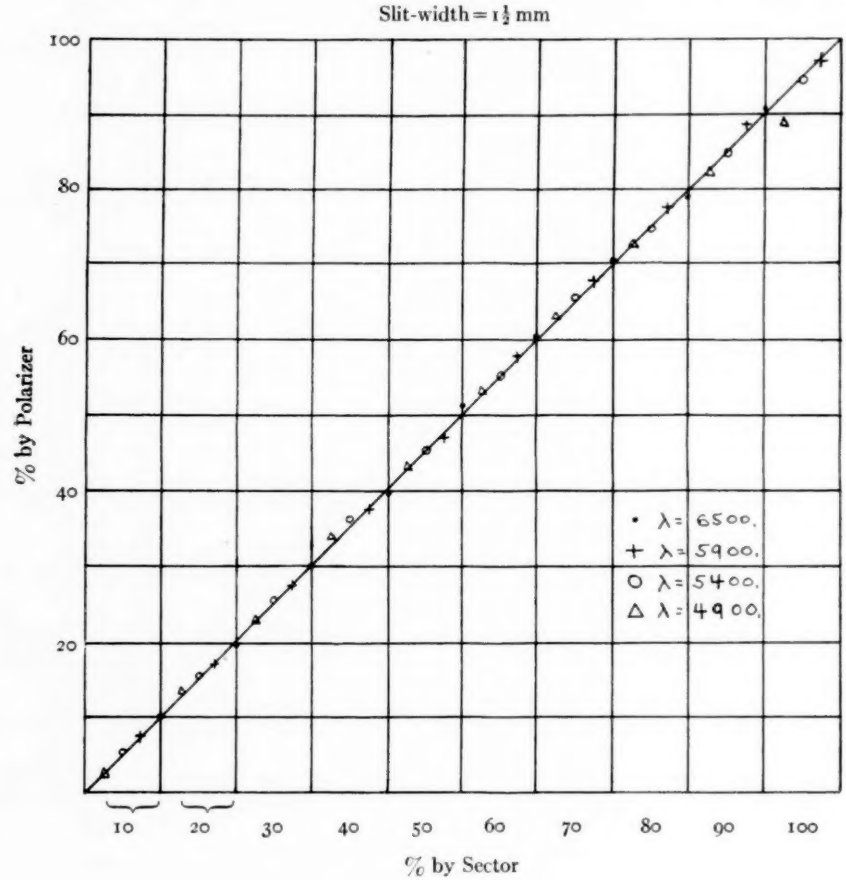


FIG. 5

sponding to a given color and represented by a given symbol (dot, cross, circle, triangle, etc.) is simply shifted with reference to all the other sets along the $45°$ line so that points are uniformly distributed over its entire length. All points are seen to fit very closely the ideal line and no systematic variation with color is dis-

cernible.[1] Fig. 5 is a similar series of observations taken with slits 1.5 mm in width, and the same remarks apply. As a final test one-half of such a series was taken, the instrument then was entirely dismounted and sent into the shops for refinishing of its mechanical and some of the optical parts. After reassembling, a different

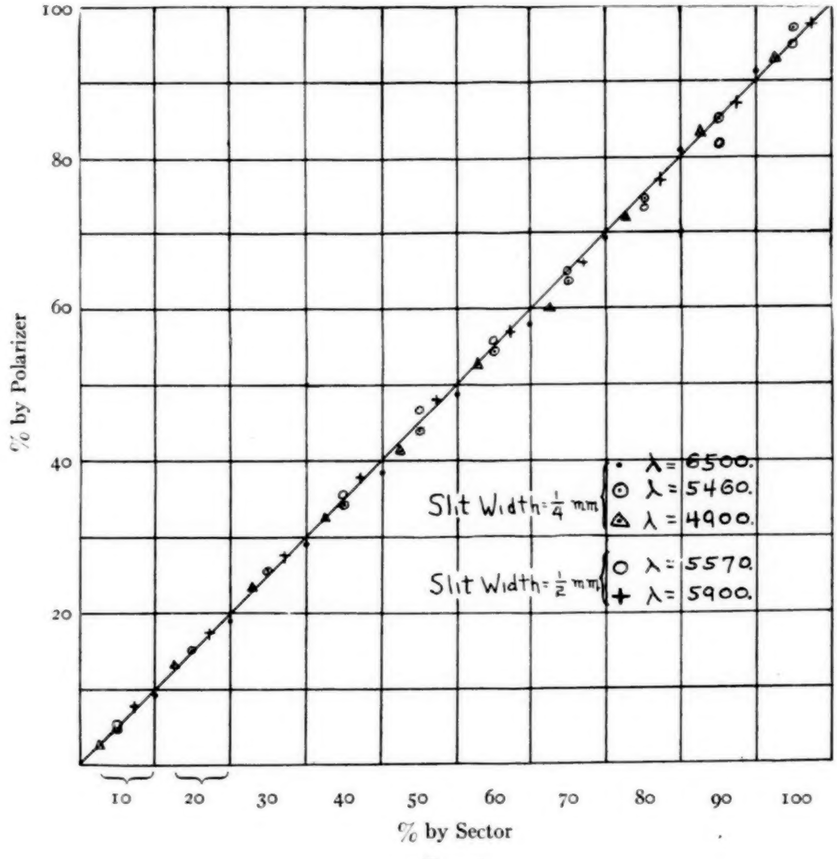


FIG. 6

Brace prism was put in, the slit-widths were made different, and the remaining half of the observations taken at different wave-

[1] Quantitative measurements of the true sector openings have not been made. The sector was carefully laid out and filed to the ruled lines. The errors are less than those of ordinary observation in intensity matches, but they begin to make appearance in measurements compiled from very extensive series of settings, such as these.

lengths from those used before. The same line fits one half of the points just as well as the other half. The departures are accidental in character and not at all systematic. Since the most unfavorable conditions possible were here imposed and speed was sought as well, each point being the mean of only five settings instead of the ten usually taken, it is not surprising that the accidental departures from the true curve are a little more than in the preceding two figures. Figs. 4, 5, and 6 show conclusively that this form of instrument needs no calibration whatever for wave-lengths, slit-width, prism, or condition of preliminary adjustments, that intensities as measured by $\sin^2 \theta$ taken directly from the average of group settings represent actual intensities. The sensibility of the instrument, provided the optical surfaces, especially those of the nicols, are carefully worked and are entirely free from minute scratches, approaches the sensibility of the human eye to differences in intensity. To sum up, then, we have in this form of instrument one in which the great economy of light furnished by the Brace prism is entirely preserved, together with the excellence of elimination of the dividing line, whereas there is *complete freedom from the cumbersome calibrations* hitherto characteristic of that instrument.

This form of photometer is put on the market by the firm of William Gaertner & Co., Chicago, to whom acknowledgments are due for the loan of an instrument for a number of years and for many mechanical changes very obligingly made as this new form was developed. Miss K. T. Aschenbrenner has been of assistance also in taking long sets of observations and aiding in their reduction.

For the benefit of those utilizing nicol prisms for controlling intensities, a table of $\sin^2 \theta$ by degrees and tenths to four places is appended. The pages are unnumbered and perforated along the edge so that they may be removed and mounted on a card for ready reference if desired.

RYERSON PHYSICAL LABORATORY
UNIVERSITY OF CHICAGO
December 1913

TABLE I

$\sin^2 \theta$ for Photometer

°	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	.0000	.0000	.0000	.0000	.0000	.0000	.0001	.0001	.0002	.0002
1	.0003	.0004	.0004	.0005	.0006	.0007	.0008	.0009	.0010	.0011
2	.0012	.0013	.0015	.0016	.0018	.0019	.0021	.0022	.0024	.0026
3	.0027	.0029	.0031	.0033	.0035	.0037	.0039	.0042	.0044	.0046
4	.0049	.0051	.0054	.0056	.0059	.0062	.0064	.0067	.0070	.0073
5	.0076	.0079	.0082	.0085	.0089	.0092	.0095	.0099	.0102	.0106
6	.0109	.0113	.0117	.0120	.0124	.0128	.0132	.0136	.0140	.0144
7	.0149	.0153	.0157	.0161	.0166	.0170	.0175	.0180	.0184	.0189
8	.0194	.0199	.0203	.0208	.0213	.0218	.0224	.0229	.0234	.0239
9	.0245	.0250	.0256	.0261	.0267	.0272	.0278	.0284	.0290	.0296
10	.0302	.0307	.0314	.0320	.0326	.0332	.0339	.0345	.0351	.0358
11	.0364	.0371	.0377	.0384	.0391	.0398	.0404	.0411	.0418	.0425
12	.0432	.0439	.0447	.0454	.0461	.0469	.0476	.0483	.0491	.0499
13	.0506	.0514	.0522	.0529	.0537	.0545	.0553	.0561	.0569	.0577
14	.0585	.0594	.0602	.0610	.0619	.0627	.0635	.0644	.0653	.0662
15	.0670	.0679	.0687	.0696	.0705	.0714	.0723	.0732	.0741	.0751
16	.0760	.0769	.0778	.0788	.0797	.0807	.0816	.0826	.0835	.0845
17	.0855	.0864	.0875	.0884	.0894	.0904	.0914	.0924	.0935	.0945
18	.0955	.0965	.0975	.0986	.0997	.1007	.1017	.1028	.1039	.1049
19	.1060	.1071	.1081	.1092	.1103	.1115	.1125	.1137	.1148	.1159
20	.1170	.1181	.1192	.1203	.1215	.1226	.1238	.1250	.1261	.1272
21	.1284	.1296	.1308	.1320	.1331	.1344	.1355	.1367	.1379	.1391
22	.1404	.1415	.1428	.1440	.1452	.1464	.1477	.1490	.1502	.1514
23	.1527	.1540	.1552	.1565	.1578	.1590	.1603	.1616	.1629	.1641
24	.1654	.1667	.1680	.1694	.1707	.1720	.1733	.1746	.1760	.1773
25	.1786	.1800	.1813	.1826	.1840	.1854	.1867	.1880	.1894	.1908
26	.1921	.1936	.1949	.1963	.1977	.1991	.2005	.2020	.2033	.2047
27	.2061	.2075	.2089	.2104	.2117	.2132	.2147	.2161	.2175	.2190
28	.2204	.2218	.2233	.2248	.2263	.2277	.2292	.2306	.2321	.2336
29	.2351	.2365	.2380	.2394	.2410	.2424	.2440	.2455	.2469	.2485
30	.2500	.2515	.2530	.2546	.2561	.2576	.2592	.2606	.2622	.2638
31	.2652	.2668	.2684	.2699	.2714	.2730	.2745	.2760	.2777	.2793
32	.2809	.2824	.2839	.2855	.2871	.2887	.2903	.2919	.2935	.2950
33	.2966	.2983	.2998	.3015	.3030	.3046	.3062	.3079	.3095	.3110
34	.3128	.3143	.3159	.3175	.3192	.3208	.3224	.3240	.3257	.3272
35	.3290	.3307	.3322	.3339	.3356	.3373	.3389	.3406	.3421	.3439
36	.3455	.3472	.3488	.3504	.3522	.3538	.3552	.3571	.3588	.3606
37	.3622	.3639	.3656	.3673	.3690	.3705	.3722	.3739	.3757	.3774
38	.3790	.3807	.3825	.3841	.3858	.3874	.3892	.3908	.3926	.3943
39	.3961	.3978	.3994	.4012	.4029	.4046	.4063	.4079	.4098	.4115
40	.4133	.4150	.4167	.4184	.4202	.4217	.4235	.4252	.4270	.4288
41	.4303	.4321	.4339	.4355	.4373	.4391	.4408	.4426	.4442	.4461
42	.4477	.4496	.4512	.4529	.4548	.4565	.4582	.4598	.4617	.4634
43	.4651	.4669	.4686	.4703	.4721	.4738	.4756	.4773	.4791	.4808
44	.4826	.4844	.4860	.4878	.4896	.4914	.4930	.4948	.4966	.4982

TABLE I—*Continued*

°	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
45	.5000	.5017	.5035	.5051	.5070	.5086	.5105	.5122	.5141	.5157
46	.5174	.5193	.5210	.5226	.5243	.5263	.5280	.5297	.5314	.5331
47	.5351	.5365	.5383	.5400	.5418	.5435	.5453	.5470	.5488	.5506
48	.5523	.5541	.5557	.5575	.5593	.5611	.5626	.5644	.5662	.5678
49	.5696	.5712	.5731	.5746	.5765	.5781	.5800	.5816	.5834	.5851
50	.5869	.5886	.5902	.5921	.5937	.5954	.5970	.5990	.6006	.6023
51	.6046	.6056	.6073	.6090	.6107	.6124	.6140	.6157	.6174	.6192
52	.6209	.6226	.6243	.6260	.6280	.6295	.6310	.6327	.6345	.6362
53	.6377	.6394	.6412	.6430	.6445	.6462	.6477	.6495	.6513	.6528
54	.6546	.6561	.6580	.6595	.6610	.6628	.6644	.6662	.6677	.6693
55	.6710	.6727	.6742	.6759	.6775	.6792	.6808	.6823	.6841	.6856
56	.6872	.6890	.6906	.6922	.6937	.6953	.6970	.6986	.7002	.7018
57	.7034	.7050	.7065	.7081	.7097	.7114	.7129	.7145	.7160	.7176
58	.7191	.7208	.7223	.7238	.7254	.7270	.7284	.7301	.7316	.7332
59	.7347	.7362	.7377	.7393	.7408	.7423	.7439	.7454	.7470	.7485
60	.7501	.7514	.7530	.7544	.7560	.7575	.7589	.7605	.7621	.7635
61	.7649	.7665	.7679	.7693	.7707	.7723	.7737	.7752	.7768	.7782
62	.7796	.7811	.7825	.7840	.7854	.7869	.7881	.7896	.7910	.7925
63	.7940	.7952	.7967	.7982	.7995	.8009	.8022	.8037	.8050	.8065
64	.8078	.8093	.8106	.8119	.8134	.8147	.8160	.8173	.8187	.8200
65	.8215	.8228	.8241	.8255	.8268	.8279	.8293	.8306	.8320	.8333
66	.8346	.8360	.8372	.8385	.8397	.8410	.8424	.8435	.8449	.8461
67	.8474	.8486	.8498	.8511	.8523	.8535	.8549	.8561	.8572	.8584
68	.8596	.8608	.8622	.8634	.8646	.8658	.8670	.8680	.8692	.8704
69	.8716	.8728	.8740	.8750	.8762	.8774	.8784	.8796	.8808	.8819
70	.8831	.8841	.8853	.8863	.8876	.8886	.8896	.8908	.8919	.8929
71	.8939	.8952	.8962	.8972	.8983	.8993	.9003	.9014	.9024	.9034
72	.9045	.9055	.9066	.9076	.9087	.9095	.9105	.9116	.9126	.9135
73	.9145	.9156	.9164	.9175	.9183	.9194	.9203	.9213	.9221	.9230
74	.9241	.9249	.9258	.9268	.9277	.9285	.9294	.9305	.9313	.9322
75	.9330	.9339	.9348	.9356	.9365	.9374	.9382	.9391	.9397	.9406
76	.9415	.9423	.9432	.9438	.9447	.9456	.9463	.9471	.9478	.9486
77	.9493	.9502	.9508	.9517	.9524	.9532	.9539	.9546	.9554	.9561
78	.9568	.9574	.9581	.9590	.9596	.9603	.9609	.9616	.9623	.9629
79	.9636	.9643	.9650	.9656	.9660	.9667	.9674	.9681	.9687	.9692
80	.9698	.9704	.9710	.9716	.9722	.9728	.9733	.9739	.9744	.9750
81	.9755	.9761	.9766	.9771	.9777	.9782	.9787	.9792	.9797	.9801
82	.9806	.9811	.9816	.9820	.9825	.9830	.9834	.9838	.9843	.9847
83	.9852	.9856	.9860	.9864	.9868	.9872	.9876	.9880	.9883	.9887
84	.9891	.9894	.9898	.9901	.9905	.9908	.9912	.9915	.9918	.9921
85	.9924	.9927	.9930	.9933	.9936	.9938	.9941	.9944	.9946	.9949
86	.9951	.9954	.9956	.9958	.9960	.9963	.9965	.9967	.9969	.9971
87	.9973	.9974	.9976	.9978	.9979	.9981	.9983	.9984	.9985	.9987
88	.9988	.9989	.9990	.9991	.9992	.9993	.9994	.9995	.9996	.9996
89	.9997	.9998	.9998	.9999	.9999	.9999	1.0000	1.0000	1.0000	1.0000

AN APPLICATION OF THE REGISTERING MICRO-PHOTOMETER TO THE STUDY OF CERTAIN TYPES OF LABORATORY SPECTRA[1]

By ARTHUR S. KING and PETER PAUL KOCH

The constantly widening use of photography as a means of recording observations, and the fact that a large proportion of such observations involve the measurement of the density of the photographic image and frequently the gradual variations of this density, give rise to exacting requirements in the application of photometry to the study of photographic plates. Instruments in use—the best known of which is probably the Hartmann micro-photometer[2]—measure with high precision the density of a restricted area of the photographic image, and can, with care and patience, be operated to show the variation of this density from point to point. There is, however, an obvious need for an apparatus which will record photographically the varying intensities of a series of objects, such as the lines in a spectrum or a set of interference rings, and show also their distance apart. This can be done if the photographic objects to be measured are made to move slowly in front of an opening through which a beam of light from a constant source is passed, and the resulting changes in the intensity of this light are recorded on a moving photographic plate. The effects obtained for such a variation in the light-energy transmitted will then correspond closely to those yielded by the recording bolometer for variations in heat-energy.

This principle is applied in the registering micro-photometer which was designed by one of the writers and constructed under his direction in the physical laboratory of the University of Munich. A detailed account[3] of its construction and of the preliminary tests has been published, together with succeeding papers[4] on the use of the instrument in various photometric studies.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 77.

[2] *Zeitschrift für Instrumentenkunde*, **19**, 97, 1899.

[3] Koch, *Annalen der Physik*, **39**, 705, 1912.

[4] *Ibid.*, **40**, 797; **41**, 115; **42**, 1, 1913.

In the summer of 1913, arrangements were made, with the ready consent of Professor Röntgen, by which this apparatus was brought by the designer to the Mount Wilson Solar Observatory and mounted in the Pasadena laboratory, where it was operated steadily for several weeks in registering intensity-curves for a variety of subjects represented in the photographs made in the different lines of investigation carried on at the Observatory. The object of the present paper is to give an account of the action of the photometer when applied to the study of several types of spectrum lines on plates made in the physical laboratory. The photographs thus examined have already been described in papers[1] on the various phenomena of the electric furnace and the tube-arc. The results of this photometric study serve to supplement the examination previously made, and also to demonstrate the usefulness of the micro-photometer in a branch of spectroscopy where quantitative measures of line-intensity and structure are highly desirable.

The observations to be described were necessarily preliminary in character and of very limited scope. The heavy demands on the instrument during the short time it was available did not permit of the repetition of slightly defective records, which would have added to the finish of the results.

APPARATUS AND METHODS

The construction of the instrument need be described only in outline here, as a detailed account[2] has already been published. A beam of light from a Nernst lamp passes through a slit, across which the photographic plate to be examined is moved by clockwork connected with the platform on which it rests. The light then passes to a photo-electric cell, which responds, by varying activity of the discharge from its potassium-coated electrode, to the change in density of the photographic plate as the latter passes across the beam of light. The other electrode of the photo-electric cell is connected to the vertical filament of a string electrometer, the plates of which are maintained at a potential difference of about

[1] King, *Contributions from the Mount Wilson Solar Observatory*, Nos. 60, 73, 76; *Astrophysical Journal*, **35**, 183, 1912; **38**, 315, 1913; **39**, 139, 1914.

[2] Koch, *loc. cit.*

200 volts. The varying charge on the filament, resulting from the changing activity of the cell, causes a horizontal movement of the filament. This movement is recorded by an image of the filament being projected on a photographic plate which moves vertically downward in a box having a horizontal slot on the side toward the electrometer. The rate of fall of this registering plate is controlled by the same clockwork that moves the plate to be registered across the illuminated slit, and the motion results in a curve being imprinted on the registering plate, the highest point of which (as the plate is usually oriented when examined) represents the maximum density of the photographic image which is being recorded. The relative rates of movement of the negative and of the registering plate are arranged to give a convenient scale for the intensity-curve. The methods of adjusting the sensitiveness according to the subject, the proper slit-widths and the reduction of inertia in the recording system have been described by the designer.

In the tests of which an account is to be given, the plates recorded were negatives made by double-copying on small plates, in order to avoid cutting the large original negatives. The plate was clamped on the moving platform of the apparatus so that the spectrum line to be recorded was parallel to the slit, which for this work was 0.038 mm wide and 1.5 mm long. The movement across the slit by means of the clock-drive then gave the variation in the light transmitted to the photo-electric cell, enabling the intensity-curve to be traced by the recording apparatus. The adjustments permitted of a ratio of either 7.65 or 46.4 between the movement of the negative and of the registering plate. The latter ratio was used throughout the present work, so that a registering plate 12 cm long gave the density-curves for a range of about 2.5 mm on the plate under examination. Except for the inconvenience of shifting the negative on its platform and piecing together the intensity-curves on the short registering plates, the apparatus as originally constructed proved well adapted to the study of the several types of spectra to be described.

The relation between electrometer deflection and density of the photographic image has been investigated,[1] and found to be almost

[1] Koch, *Annalen der Physik*, **39**, 734, 1912.

linear up to a certain degree of blackening, above which the sensitiveness of the instrument decreases rapidly as complete blackness is approached. The machine can be made to register the deflection corresponding to maximum photographic density whenever necessary if the Nernst lamp which illuminates the negative be covered for a few seconds at the beginning or end of a registration. A line showing the ordinate of total blackness will then be traced on the registering plate. The ordinates of all intensity-curves on the plate should then stop short of this height by an amount depending on the sensitiveness for which the instrument is adjusted. It can be made sensitive close to the point of maximum blackness, but in this case the illumination must be decreased for the lower part of the curve by the introduction of glass plates whose absorption is known. This somewhat difficult operation can usually be avoided by the selection of negatives of such exposure that all objects to be registered are within the range of density for which the deflection is proportional to the degree of blackening.

To place the classification of spectrum lines according to their intensity on an accurate quantitative basis, the directly measured density distributions of the photographic image must be reduced to intensity distributions, using properly chosen standards of relative intensity.[1] This presents a problem which can probably best be solved by relating the intensity distribution of the spectrum lines directly to the distribution of the black body.[2] Further, it will be important to see how far the influence of the spectrograph employed modifies the intensity distribution of the type of spectrum line under examination, and if there is need, to apply a correction for this. The latter problem is under investigation by one of the writers, the first results having been published.[3] The spectrum lines whose density curves are now to be discussed were not photographed with the data necessary to reduce the densities to intensities in a simple manner, so that the results are quantitative to a limited degree only.

[1] Koch, *Annalen der Physik*, **30**, 841, 1909; **34**, 377, 1911.

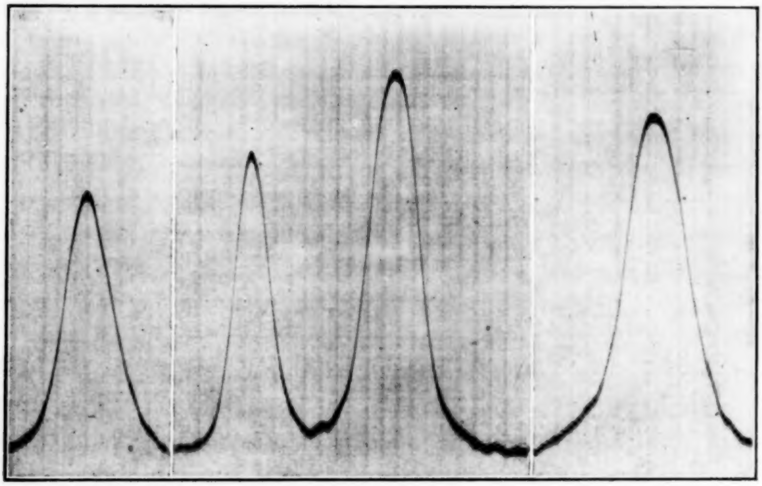
[2] *Ibid.*, **39**, 749, 1912.

[3] *Ibid.*, **42**, 1, 1913.

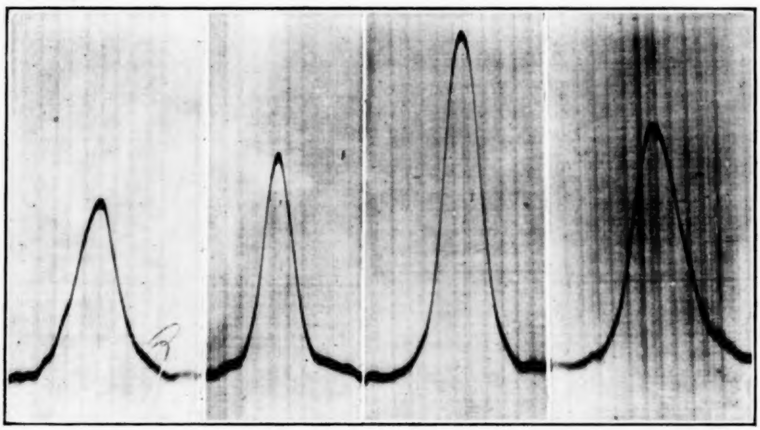
RESULTS

1. *Curves for sharp and diffuse lines.*—Values for the intensities of spectrum lines are usually given with tables of wave-length measures, very rough estimates in general being made to serve. The requirements are more exacting when the variations of line-intensities caused by changes in the physical condition of the source are considered, and any gain in accuracy in work of this kind is to be welcomed. The more distinctive differences between arc and spark spectra and between furnace spectra for different temperatures are usually well marked, and a practiced observer may attain a fair degree of accuracy in eye-estimates of intensities for lines which are similar in their distribution of intensity over the width. Serious difficulties arise, however, in the comparison of "sharp" lines with those variously described by the words "diffuse," "nebulous," "hazy," "*unscharf*," and similar terms. The latter are much wider in proportion to their density than are the sharp lines, and the eye does not readily combine the qualities of density and width so as to compare accurately lines in which these elements vary in different proportions. The purpose of the registering micro-photometer is to show, by the height and width of the density-curve, how black and how wide the spectrum line is in the negative, and also to measure by its area how much blackness is produced by the light from the line in question. Evidently this last property, if photographic differences are minimized by taking lines from the same plate, will give much closer values for the relative amounts of luminous energy emitted by the spectrum lines than can be attained by eye-estimates.

A set of lines to test the micro-photometer in this regard was selected from the arc spectrum of titanium near λ 4000 and the curves for eight typical lines, four sharp and four diffuse, are given in Fig. 1. The diffuse lines are not so extreme in this quality as can be found in other spectra, such as that of the copper arc, and the fast plate used gives a less abrupt rise at the base for the curves of the sharp lines than could be attained with greater contrast in the negative; but the typical differences, given by the gradual slope of the diffuse-line curves, resulting in a larger area in proportion to the height, are very distinct. The areas of the



λ 3895.42	λ 3901.14	λ 3900.72	λ 4030.66
Diffuse	Sharp	Sharp	Diffuse
3.6 sq. cm	2.5 sq. cm	5.1 sq. cm	6.1 sq. cm



λ 4008.21	λ 4012.55	λ 4009.82	λ 4013.72
Diffuse	Sharp	Sharp	Diffuse
2.1 sq. cm	2.0 sq. cm	3.3 sq. cm	3.1 sq. cm

FIG. 1.—Curves for sharp and diffuse lines of the titanium arc, with areas inclosed by each curve.

curves (before being reduced for reproduction) were measured by means of a transparent scale ruled in millimeter squares. These areas, in sq. cm, are given for each line.

In Fig. 1 the curves for diffuse and sharp lines are placed adjacent to each other. They were traced from lines on the same negative, with the sensitiveness of the photometer unchanged throughout. None of the lines was of maximum photographic density in any part. It is seen that for each pair the diffuse line has its maximum distinctly lower than the sharp line, but the diffuse member of the pair has the greater area, except for $\lambda\lambda$ 4009.82 and 4013.72, where the difference in height is large and the areas nearly equal. The inaccuracy of considering the density of the maximum as representing the amount of photographic action produced by a given spectrum line is quite evident, as is also the difficulty of estimating by eye to what degree the width of a diffuse line makes up for the lack in density of its center.

For lines having a similar intensity distribution over the width, the blackness of the centers will be closely proportional to the total intensities of the several lines. Thus in the lower four curves of Fig. 1 the ratio of the heights for the two diffuse lines and for the two sharp lines is in each case about 2:3, which is approximately the ratio of their respective areas. Such a proportionality does not hold for the upper four lines of this figure and there is in general enough difference in the degrees of sharpness and diffuseness of individual lines to render unsafe an estimate of the relative intensities based on the densities of the maxima, even for lines apparently of the same type. The area of the intensity-curve is in general required as the measure of the strength of a line, due regard being paid to the decrease in sensitiveness of the instrument at higher densities mentioned on p. 216.

2. *Electric furnace lines for different temperatures.*—The curves given in Fig. 2 are for strong titanium lines at temperatures of about 2400° C. and 2100° C. respectively. The areas of the curves for 2100° represent the intensities more correctly than those for the higher temperature, as the ordinates of the latter reach the height for which the sensitiveness of the instrument decreases. The unequal intensities of the members of the close

doublet λλ 4536.12 and 4536.25 at low temperature are well shown by the curves. The one-sided notching of the curve representing this doublet at 2400° shows that the difference persists in some degree at the higher temperature. The general relation shown in

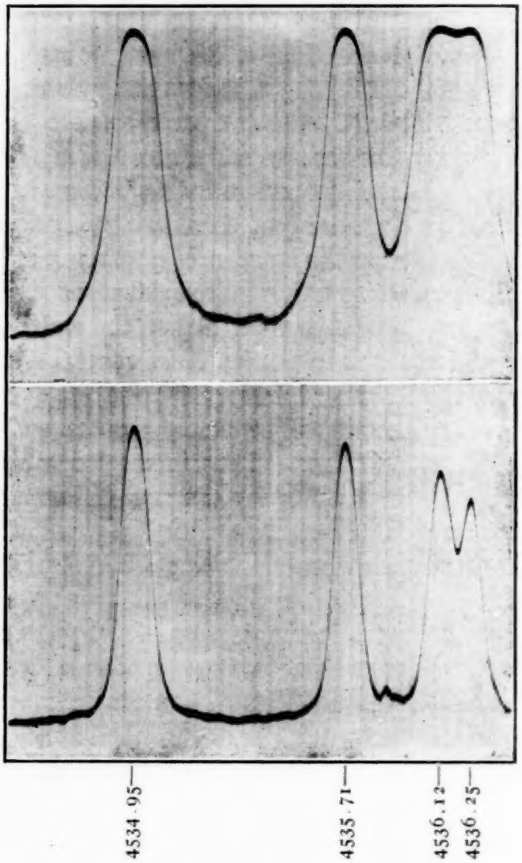


FIG. 2.—Curves for electric furnace lines of titanium, produced at 2400° C. (above) and 2100° C.

this figure is one which has been noted in the electric furnace studies of one of the writers, i.e., that low-temperature lines, when given high density by long exposure, still remain narrow; while at higher temperatures, there is a decided change in the direction of greater

width, if the exposures are timed to give the same general density at both temperatures. When the quantity of vapor is sufficient, the lines which are given at low temperature undergo a gradual softening of their centers and often pass into reversal as the temperature rises.

Time permitted the registration of only a few curves for the electric furnace spectra, and while these have shown the main problems involved in adapting the method to this work, it was not possible to carry out the experiments necessary to solve these difficulties. In addition to timing the exposures so as to obtain the proper range of density for the lines at each temperature, the varying contrasts in the negatives must be dealt with. Slight differences in contrast are given by different developments for plates of the same kind, and still larger variations are encountered in the different plates adapted to certain regions of the spectrum. To eliminate the effects of such differences will probably require the exposure of a part of each spectrum plate to lights whose relative intensities are known. Such a scale may be based on an absolute unit of light-intensity. The registration by the micro-photometer of these different degrees of blackening will then reduce the curves for spectrum lines on different plates to a common scale.

3. *Curves for lines displaced by pressure.*—The intensity distribution in spectrum lines when displaced by pressure around the source is of interest in connection with the question as to how far, if at all, the pressure-effect is to be considered as an unsymmetrical widening. It is well known that some lines become very unsymmetrical under pressure, but these belong in general to the class of diffuse lines and are probably never quite symmetrical. They show dissymmetry in the arc very readily at atmospheric pressure when the vapor density is increased or when the discharge conditions are altered. Sharp lines should be used to test the general effect of pressure, and for this purpose three sharp lines of iron, $\lambda\lambda$ 5371.734, 5397.344, and 5405.989 (the first and third being international standards of the second order), photographed with the electric furnace[1] at pressures of 8, 16, and 24 atmospheres, were

[1] King, *Contributions from the Mount Wilson Solar Observatory*, No. 60; *Astrophysical Journal*, **35**, 183, 1912.

registered by the micro-photometer. The curves for the first two lines are reproduced in Fig. 3. The total width of a line, which in this case is greatest for 16 atmospheres, bears no direct relation to the pressure, unless the conditions of the source, especially as to temperature and quantity of vapor, are kept strictly constant for different pressures. Other photographs were made at each pressure for which the lines were both wider and narrower than those reproduced here. The main point of interest is the close symmetry maintained by the reversed line at the three pressures. The degree of symmetry can be tested by means of the reference line traced by the machine during the descent of the plate, the distance of the curve from this line measuring the intensity at a given point. The line is shown for each of the curves of λ 5371.734 and for the 16-atmosphere curve of λ 5397.344, but is omitted from the two others on account of defective plates. The relative areas of the two sides of the reversed line were measured by bisecting the reversal and counting the number of millimeter squares included between the curve and the reference line for equal distances right and left until the curve became low. The areas thus measured for λ 5371.734 at the three pressures are as follows:

	Area in Sq. Cm		
	8 Atm.	16 Atm.	24 Atm.
Violet side of reversal	16.7	20.5	20.5
Red side of reversal	17.5	21.0	20.9
Difference	0.8	0.5	0.4

The small differences that appear are probably real and give slightly larger areas for the red side of the line. They are so nearly of the same magnitude that evidently there is no direct connection with the pressure. The extra area on the red side is chiefly on the outer part of the curve and may fairly be ascribed to the action of the grating, which gave a slightly hazy edge on the red side of strong lines unless the area of the ruled surface was greatly reduced.

As a result of the close approximation to symmetry for lines at these varying pressures, it is clear that the narrow line emitted by the cooler and less dense vapor near the end of the furnace tube is

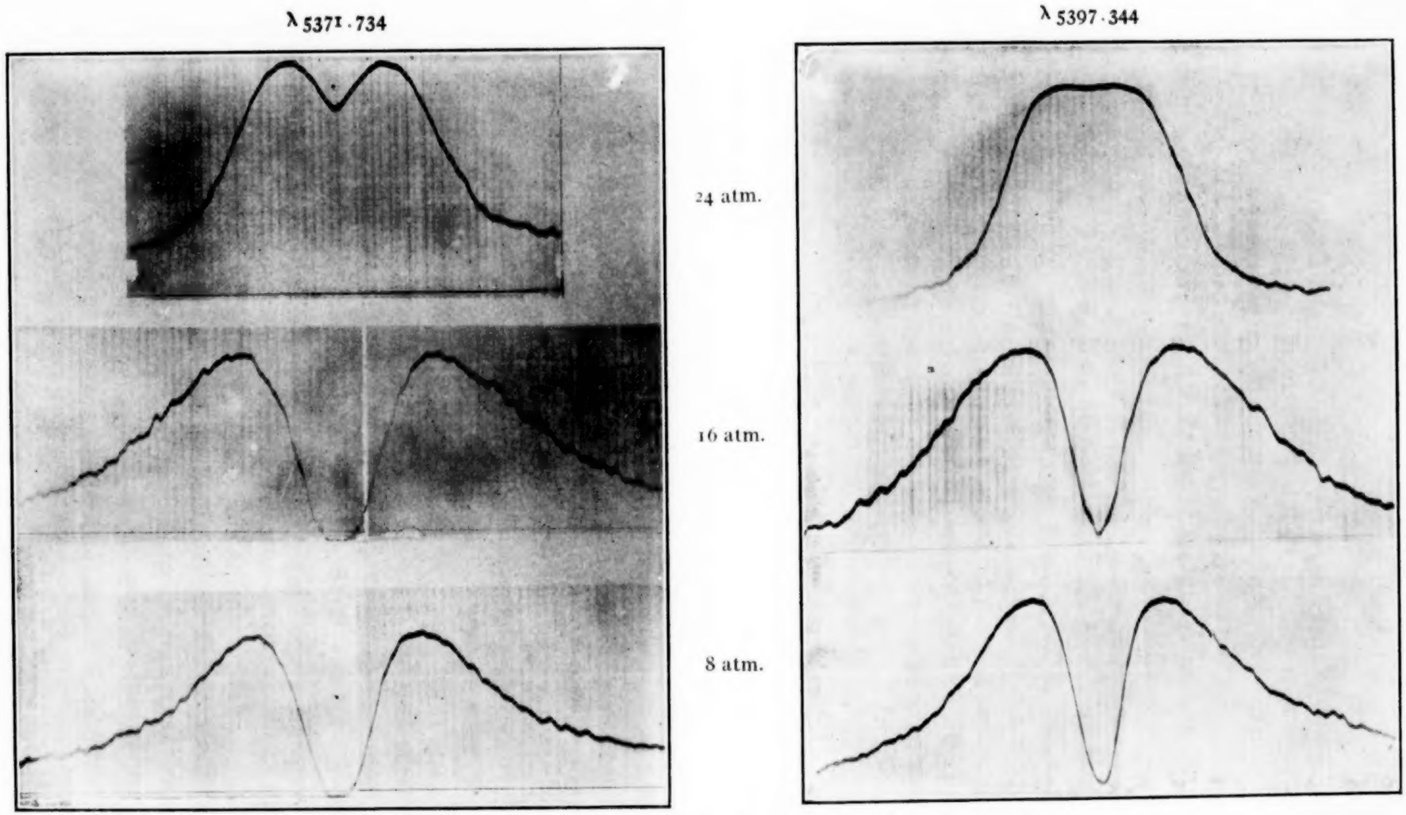


FIG. 3.—Curves for iron lines emitted by the electric furnace under pressure

displaced by pressure to the same degree as is the wider line given by the vapor near the middle of the tube's length, since the absorption of the latter radiation due to the cooler vapors gives the reversed line observed. Unsymmetrical broadening is in general much more pronounced for wide lines, and should increase with the pressure. The close symmetry which these measurements show for the reversed line at 24 atmospheres indicates a definite effect by pressure regardless of the width of lines or of the temperature or density of the vapor which produces them. This is in harmony with the conclusions previously arrived at by direct experiments[1] on variation of temperature and vapor density for given pressures, and adds to the evidence that the pressure effect is a real displacement of the maximum of the line, at least for those lines which are classed as "sharp" in spectra given with the source in vacuum or at atmospheric pressure.

4. *Intensities of reversed lines.*—The estimation by the eye of the relative intensities of reversed lines and the comparison with sharp lines involve much uncertainty. In the case of clearly reversed lines, one is inclined to lay stress on the relative widths of the reversals. This is probably safer with furnace lines than with those of other sources, by reason of the slow gradient in the condition of the vapor from center to end of the tube, which remains nearly constant during an exposure. Unless there are lines in various stages of partial reversal on the same plate, there is no simple means of connecting the intensity estimates for reversed and unreversed lines.

The registering micro-photometer promises a distinct advance in this direction. A line may be very broadly reversed, but if enough structure remains in the two sides to give its total width and the slope of the curve from the violet and red sides respectively, the central portion may be filled out by graphical methods so as to inclose an area which will represent with considerable closeness the intensity which the emission line would have if unaffected by the absorption which brings about the reversal. A reversal much wider than those shown in Fig. 3 by λ 5371.734 at 8 and 16 atmospheres would still give the intensity of the line if measured in this

[1] King, *op. cit.*, pp. 199, 202.

way, since the slope is nearly constant above a point less than half of the maximum ordinate of the curve.

5. *Intensity curves for tube-arc lines.*—From the foregoing study, it is evident that this form of micro-photometer is well adapted to show differences in structure and intensity of spectrum lines. Both of these elements vary for different parts of the same line in the case of the spectrum of the tube-arc, described by one of the writers.[1] This arc takes place when the furnace tube burns apart, causing a heavy arc current to pass at low voltage. The enhanced lines are given strongly in this source and large differences appear in lines produced at the center and near the wall of the ruptured tube.

Curves were traced with the micro-photometer for a number of typical lines given by the tube-arc when the spectrum was photographed according to the method described in the second paper, in which the slit coincided with the vertical diameter of the tube's image. The line on the negative was then about 20 mm long. By parallel diamond scratches running the length of the plate, each line was divided into four equal sections. The successive registration of these sections gave the curves shown for several lines in Fig. 4. The slit of the photometer, being 1.5 mm long, integrated the density of this length of the spectrum line, and as the tube-arc lines sometimes change rapidly both in strength and in structure over a short portion of the length, the form of the curve does not quite represent the true condition of the line at any point. The four sections are indicated by *a*, *b*, *c*, *d*, to correspond with successive parts of the line given from bottom to top of the tube's cross-section. The portion given by the axis of the tube would come between sections *b* and *c*.

The several curves of Fig. 4 may be considered in order. No. 1 represents the enhanced line of magnesium, λ 4481, which the tube-arc photographs have shown to be double, with the violet component the stronger. The photographs which gave the best definition of the components of the doublet were too strong to be used in the micro-photometer, the plate selected for this purpose

[1] King, *Contributions from the Mount Wilson Solar Observatory*, Nos. 65 and 73; *Astrophysical Journal*, **37**, 119; **38**, 315, 1913.

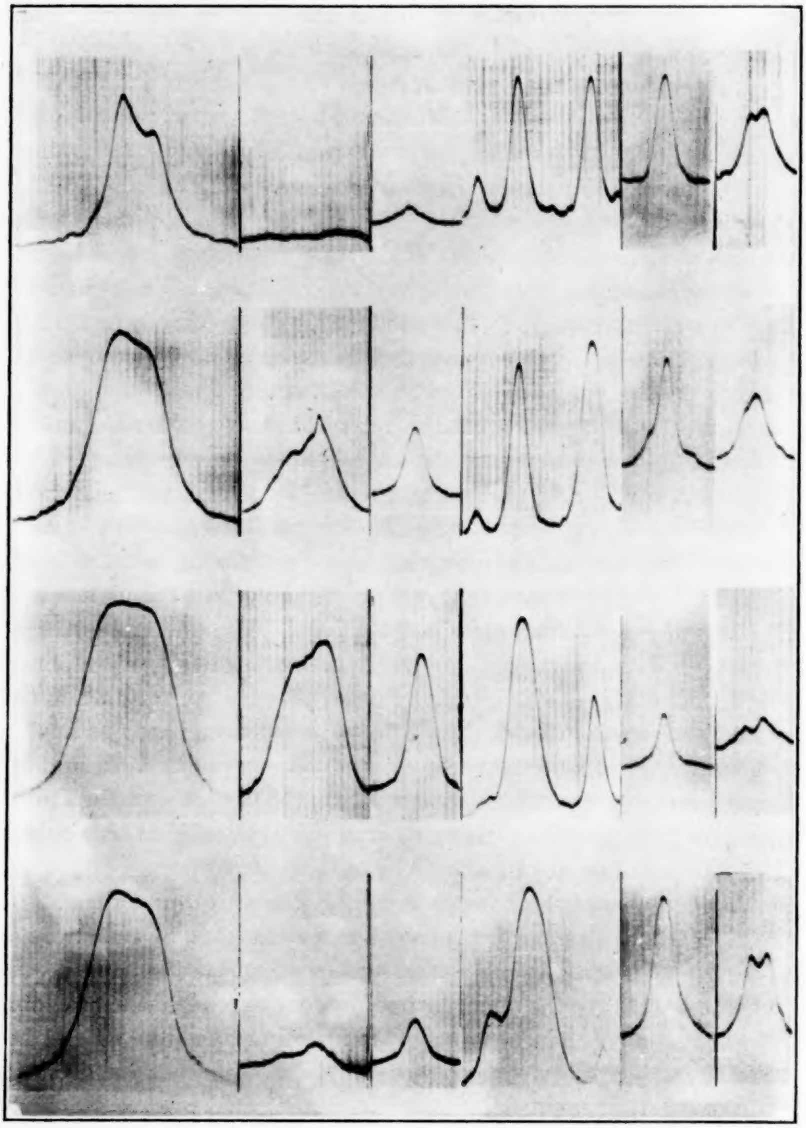


FIG. 4.—Curves for lines emitted by different parts of the tube-arc:

1. *Mg* (enhanced, double)
2. *C* (enhanced, double)
3. *Pb* (enhanced)
4. *V* (arc)
5. *Ti* (enhanced)
6. *Fe* (arc)
7. *Ti* (arc)
8. *V* (arc, reversed)

showing the components somewhat diffuse. However, the resolution is shown in *d*, while the dissymmetry toward the violet is distinct in all parts and the relative intensities of the doublet as a whole at the different heights are typical of the usual behavior of the line in the tube-arc. The greatest strength is seen to be at *b*, slightly below the center of the tube, but the line retains considerable intensity toward each end.

A much more rapid gradation from the maximum is shown by λ 4267 of carbon, represented by the curves of No. 2. This line, usually appearing only in the spark, was also shown by the tube-arc to be double, with its stronger component to the red. The dissymmetry is shown by the curves. The maximum is very distinctly at *b*, retaining some strength at *c*, and being relatively very weak at *a* and *d*, near the wall of the tube.

The enhanced line of lead, λ 4247, a symmetrical, single line, shows in No. 3 an intensity-gradation very similar to that of No. 2. These three sets of curves serve to show the variation of intensity for spark lines; the maximum enhanced-line radiation being given at the height *b*. The hydrogen lines in the tube-arc would give very broad curves, similar in relative areas to Nos. 2 and 3.

The remaining curves of Fig. 4 are for lines strong in the arc as well as in the spark. None of them shows the greatest strength at *b*, though No. 5, an intermediate type represented by the enhanced lines of titanium and vanadium, is strongest in the lower half of the tube, weakening at *c* and *d*. The iron arc line, No. 6, shows a gradation typical of the arc lines of several elements, with its maximum at *c*.

The titanium and vanadium arc lines, Nos. 4, 7, and 8, are strongest near the wall of the tube at *a* and *d*, showing a distinct minimum at *b*, where the enhanced lines are strongest. Throughout this figure, the entire curve for a given portion of a line is shown, and no attempt is made to represent the different heights from the same reference line.

The set of curves, No. 8, is of special interest, showing the variable dissymmetry in the reversal of a vanadium arc line. It is a general effect for reversed lines that the dissymmetry, when present, is most decided near the center of the tube.

These curves serve to supplement the material presented in the second paper[1] on the tube-arc phenomena, where the probable relation of the effects to those observed for the arc and spark under different conditions was discussed. It is evident that if a set of curves were traced for successive portions of the tube-arc line from end to end, with the slit of the micro-photometer as short as possible, a plot could be made with the areas of the curves as ordinates and distances along the line as abscissae which would represent with considerable accuracy the intensity variation given by different parts of the tube-arc for the line in question. Such a plot was made, from eye-estimates of the relative intensities, in the paper referred to (p. 321).

SUMMARY

The material offered in this paper is the result of a preliminary application of the micro-photometer in registering the distribution of photographic density over the width of the spectrum line. The types of lines examined have shown that the instrument may be used effectively to bring out several features which are important in the comparison of spectra.

1. A quantitative measure is obtained of the relative strengths of lines having very different appearance, especially the sharp and diffuse lines often occurring in the same spectrum, when the maximum density of the line cannot be taken as the measure of its intensity. An extension to the measurement of the intensity of reversed lines appears to be possible.

2. The characteristics of lines given at different temperatures of the electric furnace have been examined, together with the requirements necessary that spectra of this sort may be comparable for measurements of relative intensity.

3. Intensity-curves for electric furnace lines when displaced by pressure show that a line, if originally sharp, may maintain a structure very nearly symmetrical through a wide range of pressures. Thus the pressure-effect does not appear to be the result of unsymmetrical widening, and the symmetry of reversals is

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 73; *Astrophysical Journal*, **38**, 315, 1913.

further evidence of a lack of dependence on temperature or vapor density.

4. The use of the instrument in the study of tube-arc lines of different classes shows that it registers very satisfactorily the various peculiarities of intensity and structure in lines from this source.

Mount Wilson Solar Observatory
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THE FUNDAMENTAL LAW OF THE GRATING

By JANET TUCKER HOWELL

THE COINCIDENCE METHOD

The fundamental law of the grating is that $N\lambda = w\ (sin\ \theta + sin\ \phi)$ where N is the order of the spectrum, λ is the wave-length, w is the distance apart of the lines of the grating from center to center, θ is the angle between the incident light and the normal to the grating, and ϕ is the angle between the diffracted light and the normal. With the concave grating mounting used by Rowland $\phi = 0$ and the law of the grating becomes $N\lambda = w\ sin\ \theta$. It follows therefore that, for any one angle θ, $N\lambda$ is constant, and it is possible, knowing standard wave-lengths in one order, to measure the wave-lengths of lines in the superimposed spectra of other orders. This procedure, known as the method of coincidences, was used by Rowland in determining his Table of Standards; and in parts of the spectrum in which standards have not been established by independent interferometer measurements, it is still the only method for the determination of wave-lengths.

SUMMARY OF PREVIOUS WORK ON GRATING MEASUREMENTS

Kayser in his first paper on "Standards of Wave-Length"[1] took up the question of the errors in Rowland's Table of Standards. These errors are due largely to the fact that Rowland shifted different parts of the spectrum to make his solar and arc spectra agree, but Kayser thought they were due partly to a second cause, namely, the unreliability of the coincidence method, and the object of his work was to test this method. Using the method of coincidences Kayser determined the wave-lengths of a group of third-order lines from second-order standards with two different gratings and found a systematic difference in his values amounting to 0.033 A. This could be accounted for by supposing one of the gratings to have suffered a linear displacement of the rulings of one part

[1] *Astrophysical Journal*, **19**, 157, 1904.

with respect to the rest,[1] were it not for the fact that in calculating the Fabry and Perot standards by the coincidence method he found an error amounting to 0.019 A even for his better grating. As there was no reason for doubting the values of Fabry and Perot, Kayser came to the conclusion that neither of his gratings was available for coincidence work and thought it highly improbable that gratings existed perfect enough for accurate measurements by this method. He therefore confined his work on wave-length measurements to direct interpolation between Fabry and Perot standards of the same order.[2]

Since Kayser's last paper, work has been done on this subject in several directions. Papenfus in 1911[3] published two papers on the availability of the coincidence method for wave-length measurements. Working with a 13-ft. concave grating having 10,000 lines to the inch he determined the values of the tertiary standards from λ 6065 to λ 6678 by direct interpolation and from λ 4076 to λ 4376 by the coincidence method. He compared his values in both cases with Kayser's values determined by direct interpolation and found the same order of difference, which showed that no appreciable error had been introduced by the use of the coincidence method in the case of his grating.

Goos has done some recent wave-length work with a plane grating having 7000 lines to the inch.[4] He investigated the effect of varying the light-source, using first a short arc of 3 or 4 mm and then a long arc of 8 or 9 mm. With the short arc the lines were broader and when the broadening was unsymmetrical the values found with the two types of arc differed sometimes by as much as 0.02 A. So he arrives at the conclusion that a variation in the light-source used will account for large variations in the values found for tertiary standards and that before these tertiary standards can be established with any degree of accuracy a more exact definition of the standard arc is necessary.

The most recent work on tertiary standards has been done at

[1] *Ibid.*, **18**, 278, 1903. [2] *Ibid.*, **32**, 217, 1910.

[3] *Zeitschrift für wissenschaftliche Photographie*, **9**, 332, 349, 1911.

[4] *Astrophysical Journal*, **35**, 221, 1912; **37**, 48, 1913; **38**, 141, 1913.

Mount Wilson by St. John and Ware.[1] They worked both at Pasadena and at Mount Wilson and found that owing to the difference in pressure amounting to about one-fifth of an atmosphere, due to the height of Mount Wilson, some of the lines were appreciably displaced and unsymmetrically widened. The mean difference for lines suffering a great displacement amounted to about 0.05 A per atmosphere. The secondary standards were displaced only 0.006 A per atmosphere, and in the region investigated they found 25 lines which were symmetrically widened and only slightly displaced under pressure which they recommend as tertiary standards.

The work of Goos on the variation of wave-length with the length of arc and that of St. John and Ware on the displacement and unsymmetrical broadening of some lines under pressure shows that there is a chance for large errors in wave-length measurements if the experimental conditions vary to any extent. It leads one to suspect that, after all, the inadaptability of one or both of Kayser's gratings to coincidence work may not have been altogether responsible for the errors found. In calculating the Fabry and Perot standards by the coincidence method it is possible that, although the standards themselves might not be subject to any appreciable variation in wave-length, the intermediate tertiary standards used might belong to the type that is subject to displacement and unsymmetrical broadening under varying experimental conditions. As these intermediate tertiary standards lie between λ 3550 and λ 3630, a region which has not been investigated in this respect, there is as yet no conclusive evidence on this point.

There is one source of error in coincidence work for which correction should be made in any absolute determinations of wave-length. This error is due to the fact that the dispersion of air varies with the temperature. The following example will show the magnitude of the effect.

$n=\frac{\lambda_e}{\lambda}$ where n is the refractive index, λ_e is the wave-length in ether and λ is the wave-length in air. Suppose that the wave-lengths λ 5640, first order, and λ 2820, second order, coincide exactly at 0° C. and 760 mm pressure.

[1] *Op. cit.*, **36**, 14, 1912.

Then

$$\lambda_{e1} = n \times 5640 = 1.0002924 \times 5640$$

and

$$\lambda_{e2} = n \times 2820 = 1.0003091 \times 2820.$$

At 10° and 760 mm the values for n are different.

$$\lambda_1 = \frac{\lambda_{e1}}{n} = \frac{1.0002924 \times 5640}{1.0002761} = 5640.09187$$

$$\lambda_2 = \frac{\lambda_{e2}}{n} = \frac{1.0003091 \times 2820}{1.0002919} = 2820.04847$$

$$\therefore\ 2\lambda_2 - \lambda_1 = 5640.0969 - 5640.0919 = 0.005\ \text{A}.$$

So that two lines which coincide exactly at 0° C. will differ by 0.005 A at 10° C. This shows the importance of keeping the temperature constant and may account to a large extent for the variations found in measurements by the coincidence method. In exact determinations of wave-length by this method all values should be reduced to standard conditions.

The work of Papenfus showed that his grating is adapted to coincidence work and it is possible that one of Kayser's gratings may be also, but the coincidence method is far from being reinstated in the position of importance it enjoyed at the time of Rowland's work. It was with the purpose of further testing the method that the piece of work here reported was undertaken.

RESULTS OF THIS INVESTIGATION

The work consists of two parts. In the first part, using the international standards from λ 5266 to λ 5434 in the second order, I determined from them by the method of coincidences the superimposed third-order lines in this region with two gratings, one having 15,000, the other 20,000 lines per inch. This is the same region that Kayser used in comparing his 20,000- and 16,000-line gratings. My results agreed remarkably well and show that the two gratings examined are perfect enough for wave-length determinations by the method of coincidences. But this part of the work did not in itself constitute a thorough proof of the law of gratings. In the second part of my paper I have shown that it is possible, starting with one standard line and assuming the law of

gratings, to determine the value of secondary standard lines to such a degree of accuracy that it would be feasible—if the secondary standards were not already determined by independent methods—to start from one known line and build up a whole system of wave-lengths from it, provided of course that the gratings used in the work were as good as the ones with which I have been working. This second part of my work shows that a system of wave-lengths can be built up from one line by means of the coincidence method which will attain the degree of accuracy originally claimed for this method by Rowland and therefore verifies the fundamental law of gratings.

APPARATUS

After the death of Rowland his two ruling machines were not used until 1910, when they were again put into working order by Dr. J. A. Anderson. Several of the gratings ruled last year by Dr. Anderson have been at my disposal. I have had therefore exceptional opportunities for carrying on grating work. I only regret that I have not had the time to test a larger number of them in the same and in different directions. In the first part of my work, comparing tertiary standards obtained by the coincidence method with two gratings, I used one of Rowland's six-inch concave gratings with a 21-foot radius and 20,000 lines to the inch, and one of Anderson's six-inch concave gratings with approximately the same radius and 15,000 lines to the inch. In the second part of my work it was necessary to work with superimposed spectra of higher orders, so I used one of Anderson's concave gratings having a radius of 21 feet and 7,500 lines per inch.

The grating mounting was that used by Rowland and Jewell in their work. The experimental conditions were kept as constant as possible, so that any line-displacement due to a variation in the light-source would occur to the same extent throughout the work. In the event therefore of a standardization of the light-source to be employed in wave-length measurements, my values could not be used for tertiary standards. They are, however, correct in relation to each other and this is all that is necessary in comparing the values obtained from different gratings in a proof of the coincidence method. The iron arc used was about 4 mm long and was operated at 110 volts with a direct current of between 5.5 and 6.5 amperes.

Owing to the fact that the Johns Hopkins University is situated in the middle of a city, it was found impossible to use plates taken in the daytime, as the vibrations due to the traffic seriously impaired the sharpness of the lines. All the plates used for measurement were therefore taken between 12 P.M. and 6 A.M. The method of measuring the plates was as follows: The secondary standards λ 5266.569 (group *d*) and λ 5434.527 (group *a* of Gale and Adams) were used to determine the scale of each plate in the second order. Using the scale thus determined, the values of the intermediate standard lines λ 5371.495 (group *a*) and λ 5405.78 (group *a*) were calculated. From the differences between the calculated and standard values a calibration-curve of each plate was drawn from

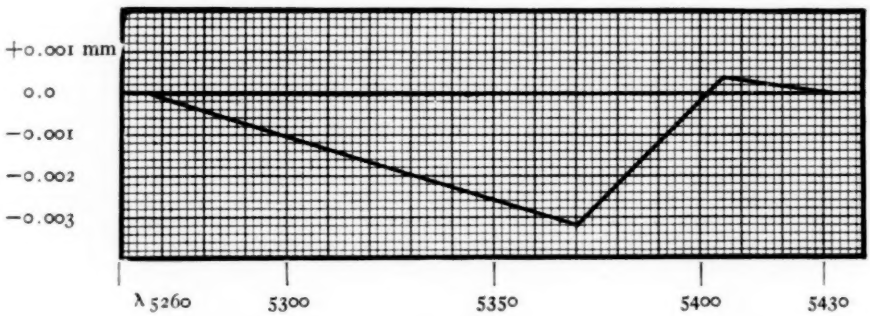


FIG. 1.—Typical calibration-curve for a plate between λ 5266 and λ 5434

which the readings for all other lines were corrected. A typical calibration-curve is shown above in Fig. 1.

The measuring engine was specially constructed for use in this piece of work. The screw was ground by the Rowland method until all periodic errors were sufficiently eliminated for the purpose and it was estimated that the errors outside of the error of the screw did not amount to more than one-fifth of a division on the head of the screw. One division on the screw-head = 0.001 mm and, as it was found impossible to count on successive readings agreeing to within less than 0.005 mm, the error of the instrument is negligible in comparison with the error of setting on a line. The readings were made to thousandths of a millimeter, and from twelve to fifteen readings were made on each line. The plates

were reversed after the whole region had been measured in one direction three times.

The scale of my plates was such that for the 20,000-line grating 1 mm = 0.9702 A and for the 15,000-line grating 1 mm = 1.30729 A, in the second order. After correcting the readings for each line from the calibration-curve of the plate the wave-lengths of the lines were found in terms of this scale in the second order and then reduced to third-order values by multiplying by the factor $\frac{2}{3}$.

FIRST PART—RESULTS

The region between λ 5266 and λ 5434 was measured as described above. In this region there is only one second-order line which is on the list recommended by St. John and Ware as tertiary standards. It was therefore the only second-order line I measured, and my values are given below in Table I, together with those obtained by other observers. This line belongs to group *a* in the classification of Gale and Adams.

TABLE I

20,000 Grating	15,000 Grating	Kayser	Goos	St. John
5429.7005	5429.7001	5429.701	5429.700	5429.702

As there was no way of telling which of the third-order lines were the best for this work and the least affected by varying experimental conditions, I measured all those which were sharp on both sets of plates. The reading for any one line on one plate did not differ from the mean value of the four plates used by more than 0.003 mm. The greatest difference found between the values of any third-order line calculated by the two gratings amounted to 0.005 A, a difference which occurs only once in the 47 lines measured. The sum of the differences amounts to +0.0620 and −0.0237 A, the average difference being only $+\frac{0.0383}{47} = +0.0008$ A and the average variation $= \pm\frac{0.0857}{47} = \pm 0.0018$ A. So the difference between two lines measured on different gratings by the coincidence method is of the same order of magnitude as the

difference between values of the same line measured on different plates. This proves that the two gratings employed were perfect enough to be used in wave-length measurement by the coincidence method. The tabulated results are given in Table II.

TABLE II

20,000 Grating	15,000 Grating	Difference	Kayser	Rowland
3513.8220	.8226	+0.0006	.821	.97
3521.2669	.2674	+ .0005	.26	.41
3524.0803	.0809	+ .0006	.07	.22
3524.2463	.2469	+ .0006	.24	.39
3526.0470	.0453	− .0017	.03	.18
3526.1705	.1721	+ .0016	.23	.38
3526.3843	.3839	− .0004	.38	.53
3526.6785	.6806	+ .0021	.66	.81
3527.7999	.8033	+ .0034	.78	.93
3529.8235	.8265	+ .0030	.80	.95
3533.0115	.0103	− .0012	.00	.15
3533.2028	.2057	+ .0029	.19	.34
3536.5597	.5632	+ .0035	.55	.70
3540.1314	.1349	+ .0035	.12	.27
3541.0925	.0939	+ .0014	.09	.24
3542.0819	.0787	− .0032	.08	.23
3545.6437	.6487	+ .0050	.62	.77
3553.7459	.7432	− .0027	.72	.87
3554.1250	.1238	− .0012	.11	.26
3554.9299	.9265	− .0034	3554.92	3555.07
3556.8822	.8831	+ .0009	3556.880	3557.03
3558.5213	.5211	− .0002	.52	.67
3565.3862	.3880	+ .0018	.38	.53
3570.1049	.1045	− .0004	.12	.27
3571.9985	.9968	− .0017	3572.00	3572.15
3575.3745	.3750	+ .0005	.35	.50
3581.2017	.2024	+ .0007	.20	.35
3582.2069	.2061	− .0008	.19	.34
3584.6657	.6672	+ .0015	.65	.80
3584.9628	.9636	+ .0008	3584.96	3585.11
3585.3255	.3274	+ .0019	.32	.47
3585.7118	.7142	+ .0024	.71	.86
3586.1172	.1165	− .0007	.11	.26
3586.9921	.9918	− .0003	3586.97	3587.12
3589.1115	.1103	− .0012	.10	.25
3594.6419	.6397	− .0022	.62	.77
3603.2095	.2106	+ .0011	.20	.35
3605.4595	.4615	+ .0020	.47	.62
3606.6846	.6865	+ .0019	.682	.83
3608.8645	.8621	− .0024	3608.85	3609.01
3610.1584	.1597	+ .0013	.16	.31
3612.0805	.0851	+ .0046	.08	.23
3617.7899	.7939	+ .0040	.78	.93
3618.3899	.3923	+ .0024	.38	.53
3618.7723	.7730	+ .0007	.77	.92
3621.4634	.4655	+ .0021	.46	.61
3622.0061	.0088	+ .0027	.00	.15

SECOND PART—THEORY

In this part of my work I have tried to furnish a real proof of the accuracy with which the fundamental law of the grating holds. The grating used in this part was one of Anderson's with 7,500 lines to the inch and a radius of 21 feet. For my fundamental line I chose λ 5232.957, one of the international secondary standards (group *d*) and proceeded as follows to determine the scale of my plate, knowing

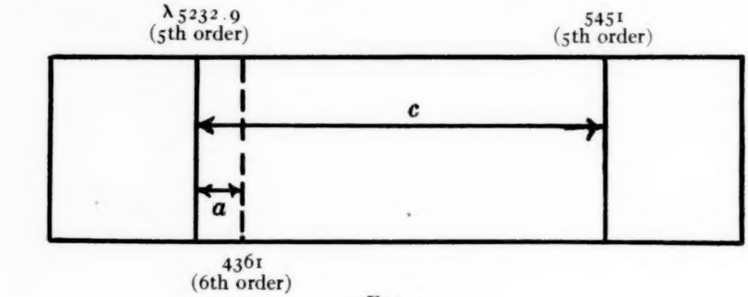


Fig. 2

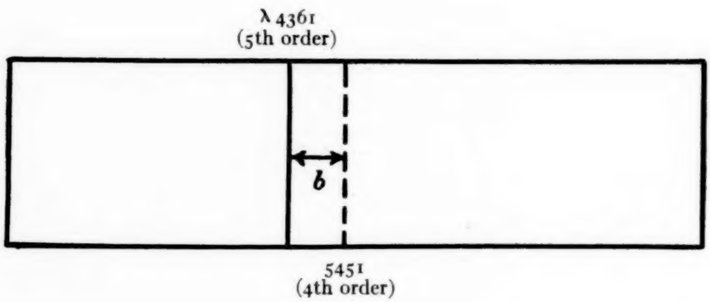


Fig. 3

only this one wave-length and the law of gratings. I first photographed this line in the 5th order. A plate of this type is illustrated in Fig. 2. On Fig. 2 we know the wave-length of line λ 5232.957 in the 5th order. Near it is a line in the 6th order which we shall call 4361, although its wave-length is not known. The distance between λ 5232.957 (5th) and 4361 (6th) is *a* mm. Then, if x mm $=1$ A in the 5th order,

$$\text{the distance } a=\frac{a}{x}\text{ A.}$$

The wave-length of the line 4361 will then be $\lambda_1 = (5232.957+\frac{a}{x})$ A in terms of the 5th order, which gives

$$\lambda_1=\left[5232.957+\frac{a}{x}\right]\tfrac{5}{6}\ \mathrm{A}$$

in the 6th order.

The grating is now shifted so as to bring the line 4361 in the 5th order on the middle of the plate. A plate of this type is illustrated in Fig. 3. At *a* distance *b* mm from 4361 in the 5th order there will be a line in the 4th order which we shall call 5451. This line also occurs on Fig. 2 in the 5th order at a distance *c* mm from λ 5232.957, the standard line:

$$b=\frac{b}{x}\ \mathrm{A}$$

in the 5th order

$$\therefore\ 5451=\lambda_2=\left[5232.957+\frac{a}{x}\right]\tfrac{5}{6}+\frac{b}{x}\mathrm{A}$$

in the 5th order

$$\lambda_2=\left(\left[5232.957+\frac{a}{x}\right]\tfrac{5}{6}+\frac{b}{x}\right)\tfrac{5}{4}\ \mathrm{A}$$

in the 4th order.

Also from Fig. 2,

$$\lambda_2=5451=\left(5232.957+\frac{c}{x}\right)\mathrm{A}$$

in the 5th order

$$\therefore\ \left(5232.957+\frac{c}{x}\right)=\left(\left[5232.957+\frac{a}{x}\right]\tfrac{5}{6}+\frac{b}{x}\right)\tfrac{5}{4}$$

$$\therefore\ 5232.957x=24c-25a-30b$$

$\therefore\ x=$ no. of mm per A in the 5th order

$$x=\frac{24c-25a-30b}{5232.957}.$$

In practice I used four lines in the neighborhood of λ 5232.9 instead of the one referred to above as 4361. Then for the line given as 5451 I used one of the international standards, λ 5455.614 (group *a*), so that my scale, obtained entirely by the coincidence method, might more easily be compared with the scale obtained directly from the two standards λ 5232.957 and λ 5455.614. In order to identify the lines it was of course necessary to take plates

with color-filters to cut out all except certain orders. I then took four plates of Fig. 2 and four of Fig. 3. The values for b for each of the four lines used in place of 4361 were then averaged for the four plates of Fig. 3, each line being read nine times. These average values for b were then used with the different values for a and c obtained from each of the four plates of Fig. 2. The values for a and c and the average values of b are given in Table III. The four lines used for 4361 are denoted by the symbols I, II, III, IV. On two plates there were only three lines good enough for accurate measurement.

The values for x, the number of mm per angstrom in the 5th order are given in Table IV. The subscripts I, II, III, IV indicate which of the four lines was used in obtaining x and the mean value of x obtained by the method of coincidences is then compared with x (standard), the value found by assuming the two international secondary standards λ 5232.957 and λ 5455.614 in the usual way.

The greatest error for the scale of the plates determined by this method amounts to one part in a hundred thousand and the mean error to three parts in a million. It is easier, however, to judge the method by comparing the values for the standard line λ 5455.614 as found by the coincidence method with the accepted value as found by independent interferometer measurements. This comparison is made in Table V.

We therefore see that the maximum error introduced by calculating one standard line from another by the method of coincidences is 0.0029 A and the mean error amounts to only 0.0007 A.

In calculating the line λ 5455.6 from the original line λ 5232.9 there has of course been no calibration-correction made. But even in starting with a set of the international standards it is necessary to use two of them without calibration-correction of any kind in order to get the scale of the plate. In order to carry out the scheme of building up a whole system of wave-lengths from one line it would be necessary, after establishing a second line in the manner described above, to determine the intermediate standard lines by coincidences in the same way, starting from each of the two fundamental standards as base line and also from each new

standard as it is determined. In this way, by averaging the results, each line will be established with sufficient accuracy to be used as a standard line and from these standards a calibration-curve may

TABLE III

	I	II	III	IV	
Plate I(*a*)					
a.........	− 9.2226	+7.7708	+17.3393	+26.0642	
b.........	+11.2161	−2.9545	−10.9239	−18.1977	
c.........	....	....	....	....	212.5546
Plate I(*b*)					
a.........	− 9.2228	+7.769	+17.342	+26.0616	
b.........	+11.2161	−2.9545	−10.9239	−18.1977	
c.........	....	....	....	....	212.5507
Plate I(*c*)					
a.........	....	+7.7761	+17.3419	+26.067	
b.........	....	−2.9545	−10.9239	−18.1977	
c.........	....	....	....	....	212.550
Plate I(*d*)					
a.........	− 9.2215	....	+17.3412	+26.066	
b.........	+11.2161	....	−10.9239	−18.1977	
c.........	....	....	....	....	212.5534

TABLE IV

Plate	$X_{(I)}$	$X_{(II)}$	$X_{(III)}$	$X_{(IV)}$	X_{mean}	$X_{standard}$	Difference
I(*a*).....	0.954607	0.954656	0.954631	0.954649	0.954636	0.954628	−0.000008
I(*b*).....	.95459	.954614	.95460	.954614	.954604	.954610	+ .000006
I(*c*).....	....	.954598	.95461	.954614	.954607	.954610	+ .000003
I(*d*).....	0.954595	....	0.954617	0.954618	0.95461	0.95462	+0.00001

TABLE V

Plate	$C_{(mm)}$	$\frac{c}{x_{mean}}=C_A$	$5232.957+C_A$ St. Line Calc.	Standard I.A.	Difference from St. 5455.614
I*a*—.........	212.5546	222.6553	5455.6123	5455.614	−0.0017
I*b*—.........	212.5507	222.6585	5455.6155	5455.614	+ .0015
I*c*—.........	212.550	222.65707	5455.61407	5455.614	+ .00007
I*d*—.........	212.5534	222.6599	5455.6169	5455.614	+0.0029

be drawn for the plate. Then the other lines of all the superimposed spectra in the region can be determined. These lines will give starting-points for similar work in other parts of the spectrum. Of course as the steps involved in the work carry one farther and

farther from the two original lines, errors might accumulate to a very appreciable extent, but at the same time every new line that is established will give another reference line from which the next lines may be determined. So that by tying up each new line by coincidences with many other lines, some of greater, some of less, wave-length, the errors introduced will offset each other.

My original intention in taking up this work was to build up, in some part at least, a system such as this. To build up an entire system, determining each line with a sufficient number of coincidences to insure the desired accuracy, would be a stupendous task. It would also be an unnecessary one, because the values obtained for the standard lines could not obtain an accuracy greater than that of the international system. It is therefore simpler to use these standards to begin with. I have shown, however, that, having these standards throughout part of the spectrum, it is possible to investigate the region into which they do not extend by means of the coincidence method with an accuracy as great as has been obtained as yet in wave-length determination by direct interpolation. Before a grating can be used for this work it must be tested by the method given in Part II of this paper in order to see how closely it obeys the law of gratings. The results obtained with my three gratings have been so good that it is perhaps not too much to say that a grating which is unfit for coincidence work is the exception and not the rule.

In conclusion I wish to thank Dr. J. S. Ames and Dr. J. A. Anderson, under whose direction this research has been conducted, for the help and advice they have given me and the interest they have taken in my work.

Johns Hopkins University
June 1913

THE INFRA-RED ABSORPTION SPECTRA OF SOME ALKALOIDS

BY B. J. SPENCE

During the last two decades an extended study of the absorption of many chemical compounds has been made by various investigators. The field has been not only that covered by the visible spectrum, but the ultra-violet and the infra-red regions have been subjected to close scrutiny. The attempt has been chiefly to relate absorption spectra to molecular or atomic grouping and also to relate a variation in the absorption spectra to a variation in molecular or atomic groupings. The attempts have not been as fruitful and the results as clearly defined as one would perhaps anticipate. The infra-red region possesses an advantage which the ultra-violet and visible regions do not, namely, that of extent, consequently the infra-red is more likely to yield data for any given substance from which inferences may be drawn.

Organic compounds have been the chief source of study owing to their variety and in many instances to their apparently simple molecular groupings. Coblentz (*Carnegie Institution Publications*, No. 35) has made a systematic study of a large group of substances and his results taken in conjunction with those of other investigators have led to many interesting conclusions, but the question as to the relation of molecular groupings and absorption spectra has been by no means clearly established. The field of investigation covered has not been complete, in fact only a small portion of the whole has been worked over. Perhaps with additional data, more concise statements may be made as to the relationship of absorption and molecular constitution.

The ultra-violet absorption spectra of many of the so-called alkaloids were studied by Hartley (*British Association Report*, 1901). His work in the ultra-violet region was both comprehensive and searching, and the constitution of many compounds was established by this method where chemical methods have failed. He not only located the position of the absorption bands but

measured the absorption limits at decreasing concentration until complete transmission was obtained. The infra-red absorption cannot be studied in this manner owing to the lack of diathermanous solvents for the alkaloids, yet it possesses the advantage of extent, namely, from 0.5μ to 15μ, the working limits of the rock-salt prism.

The study of the alkaloids about to be described was undertaken chiefly because the alkaloids constitute a large group of organic substances showing alkali reaction and basic properties similar to ammonia. They contain carbon, hydrogen, and nitrogen and most of them contain oxygen. Those studies were, generally speaking, derivatives of pyridine, pyrrolidine, quinoline, and piperidine and contain the pyridine ring. Behaving like ammonia, they combine directly with acids to form salts without the elimination of water and hydrogen.

The alkaloids studied were divided into four groups (Richter, *Organic Chemistry*, **2**), namely, the pyridine, quinoline, tropine, and isoquinoline groups. They were particularly chosen owing to the fact that like the benzene derivatives they have much in common in their deportment. The number in each group studied was limited largely by the fact that many of them could not be obtained or put into such a form that transmission was not accompanied by scattering or diffusion.

APPARATUS

The investigation was carried on by means of a spectrometer of special design, constructed by the university mechanician. The chief feature of the instrument was that it did not possess the customary divided circle. The divided circle was replaced by a carefully turned disk and rotated by an invar strap attached to one point of its periphery. One end of the strap was fastened to the nut of a carefully ground screw, which when turned drew the nut forward or backward, thus rotating the disk. The screw had fastened to one end a disk graduated in degrees. To the other end of the strap was fastened a weight which served to take up at all times the slack of the invar strap. This combination was constructed so that a rotation of the graduated disk through an angle of one degree rotated the disk replacing the divided circle through an arc of five seconds.

The rock-salt prism and mirror were placed on the disk replacing the divided circle and adjusted according to the method described by Wadsworth (*Philosophical Magazine*, **38**, 1904). The rock-salt prism was one with a 60° angle and faces 40×50 mm. The concave mirrors were of 50 cm focal length and of 5 cm aperture.

The recording instruments were a thermopile and galvanometer. The galvanometer was the four-coil Thomson astatic system type similar to one described previously (*Physical Review*, **28**, 1909) except that, instead of being shielded by the heavy soft iron cylinders, this one had its coils imbedded in a soft iron core which effectually performed the same function as the cylinders.

The thermopile used was similar to one described by the author (*Physical Review*, **1**, 1910) but was somewhat better adapted to precision work. Instead of being bound together by ivory strips, it was held together by pieces of paper shellacked to the sides of the thermopile. This gave the instrument sufficient rigidity and decreased the thermal capacity to a large extent. The thermopile-galvanometer-spectrometer combination was of sufficient sensibility to give a galvanometer deflection of 35 mm in the region of 12 μ with the galvanometer-scale at a distance of a meter from the galvanometer. The source of light was a Nernst glower burning at normal power and the width of the spectrometer slit was 0.7 mm. At this sensibility the galvanometer-thermopile combination assumed a steady deflection almost immediately and returned to its initial zero position almost immediately.

The instrument was calibrated by means of the known dispersion constants of rock salt and the angle of the prism. As a means of verification of the calibration, the absorption spectra of films of selenite, mica, and collodion were obtained with the instrument and these spectra compared with the spectra of the same substances obtained by others. The two calibrations were in as perfect accord as could be determined.

EXPERIMENTAL

In order to proceed with the study of the absorption spectra it was necessary to get the substances in some clear form before the spectrometer slit. This was the chief source of difficulty. When the substances were in liquid form, it was an easy matter to include the liquid between two rock-salt plates separated by tin foil. When

the substances were in the solid state and possessed melting-points such that melting took place without decomposition, they could be melted between two rock-salt plates, and a thin film obtained by this means. Many substances crystallized to such an extent upon solidification that the film scattered the light so greatly that this means of preparing the film was prohibited. Some substances could be dissolved in ether and this solution spread over the rock salt a sufficient number of times to obtain a film of minute crystals in which scattering was not too great.

The rock-salt plates were fastened to a carrier so that the film could be drawn before the slit at will. The absorption of the rock salt was eliminated by drawing before the slit the plate containing the film and then replacing this plate and its film by another plate or plates equivalent in thickness to the salt plate containing the film. The ratio of the two galvanometer deflections obtained by these operations gave the transmission of the film under consideration for a particular wave-length.

Table I states the groups of alkaloids studied, the alkaloids studied under each group, and the position of the absorption bands found for each. With the pyridine group were studied the non-alkaloidal substances pyridine and α-picoline.[1] These were studied to learn whether any relation existed between them and the alkaloids of that group. More particularly pyridine was studied because the alkaloids of this group are derivatives of it. Then α-picoline was studied owing to its relation to pyridine. It is known as a homologous pyridine.

Under the tropine group are included the substances benzoic acid and cocaine hydrochloride. Benzoic acid was studied because cocaine yields, when treated with hydrochloric acid, ecgonine and benzoic acid as two of its decomposition products; the point being that cocaine hydrochloride might show bands characteristic of these. This would undoubtedly be true should cocaine hydrochloride proceed so far in its decomposition that these two products were present. It is also to be mentioned here that belladonna is composed of two closely related alkaloids, hyocine and hyoscyamine, both belonging to this group.

[1] These have also been recorded by Coblentz.

TABLE I

Pyridine Group

Pyridine*	C_5H_5N	3.25, 5.22, 6.35, 6.95, 8.32, 8.80, 9.50, 9.77, 10.15.
Piperidine	$C_5H_{10}NH$	3.45, 6.10, 6.93, 7.60, 7.97, 8.75, 9.10, 9.65, 10.70, 10.90, 11.60.
Coniine	$C_8H_{17}N$	3.45, 6.15, 6.40, 7.00, 7.45, 9.05, 9.65, 10.25, 10.55, 10.85, 11.30.
Nicotine	$C_{10}H_{14}N_2$	3.63, 6.42, 7.05, 7.62, 8.45, 9.18, 9.81, 11.15.
Pilocarpine	$C_{14}H_{16}N_2O_2$	3.15, 5.75, 6.88, 7.37, 8.20, 8.60, 9.10, 9.80, 10.20, 10.70.
Piperine	$C_{17}H_{19}NO_2$	3.42, 6.25, 6.90, 8.03, 8.98, 9.80, 10.05, 10.55, 10.80, 11.25, 11.65.
α-Picoline*	C_6H_7N	3.40, 5.25, 6.32, 6.92, 7.85, 8.80, 9.20, 9.70, 10.10, 10.35.

Tropine Group

Atropine	$C_{17}H_{23}NO_3$	3.32, 5.82, 6.90, 7.40, 8.35, 8.60, 9.45, 9.72, 10.20, 10.70, 10.85, 11.33.
Cocaine	$C_{17}H_{21}NO_4$	3.43, 5.85, 6.90, 7.95, 9.10, 9.75, 10.12, 10.72.
Cocaine HCl	$C_{16}H_{21}NO_4(HCl)_2$	3.25, 5.90, 6.95, 7.95, 9.05, 9.95.
β-Eucaine	$C_{17}H_{21}NO_2$	3.80, 5.97, 6.42, 6.95, 7.32, 7.95, 9.12, 9.40, 9.88, 10.18, 10.65, 11.12, 11.20.
Ecgonine HCl	$C_9H_{15}NO_3HCl$	3.60, 5.95, 7.05, 7.75, 8.35, 9.00, 9.70, 11.20.
Homatropine	$C_{16}H_{21}NO_3$	3.40, 5.75, 6.85, 8.35, 9.12, 9.70, 10.33, 10.80, 11.50.
Belladonna		3.10, 6.00, 7.00, 8.40, 9.57, 9.80, 10.30, 10.85, 11.45.
Benzoic Acid	$C_7H_6O_2$	3.57, 5.92, 7.03, 7.75, 8.58, 8.94, 9.45, 9.80, 10.72.

Quinoline Group

Quinoline*	C_9H_7N	3.25, 5.25, 6.35, 6.80, 7.62, 8.15, 8.90, 9.77, 10.55.
Quinine	$C_{20}H_{29}N_2O_2$	3.25, 6.15, 6.82, 7.48, 8.10, 9.15, 9.72, 10.08, 10.35, 10.75, 11.00, 11.35, 11.70.
Quinine Sulphate	$(C_{20}H_{24}N_2O_2)_2 \cdot H_2SO_4$	3.63, 6.10, 6.88, 7.45, 8.15, 8.88, 9.75, 10.90, 11.65.
Brucine*	$C_{23}H_{26}N_2O_4$	3.40, 4.85, 6.03, 6.97, 7.87, 8.32, 9.05, 9.62, 9.85, 10.85, 11.30, 11.70.
Chinconidine	$C_{19}H_{22}N_2O$	3.50, 6.30, 6.88, 7.50, 8.10, 9.15, 9.95, 11.15.
Quinidine		3.32, 6.25, 6.88, 7.57, 8.10, 9.05, 9.80, 10.05, 11.07.

* Coblentz, *Pub. Carn. Institution*, No. 35.

TABLE I—*Continued*

ISOQUINOLINE GROUP

Codeine.........$C_{18}H_{21}NO_3$......3.45, 6.35, 6.95, 7.33, 8.00, 9.10, 9.65, 10.37, 10.65, 10.95, 11.45.

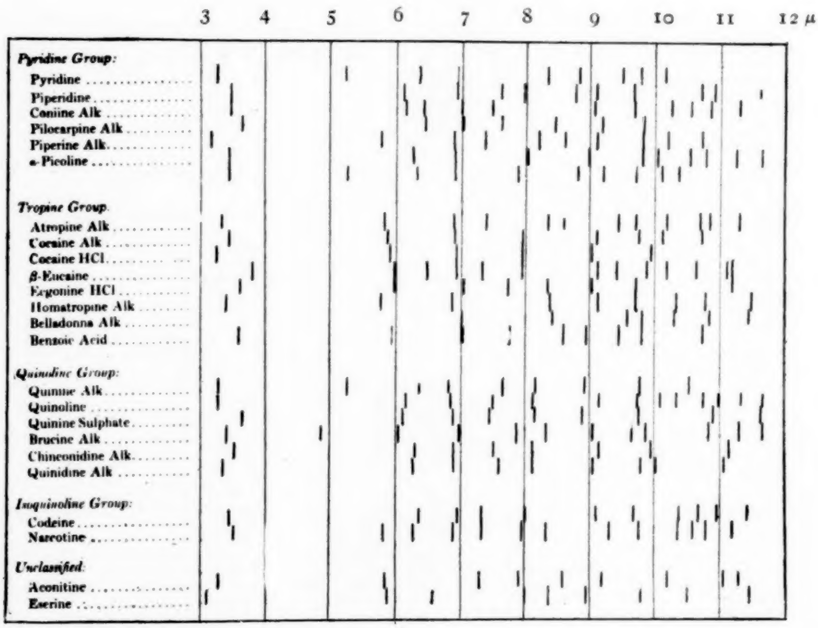
Narcotine.......$C_{22}H_{23}NO_7$......3.50, 5.77, 6.25, 6.88, 7.32, 7.95, 8.32, 9.32, 9.75, 10.35, 10.77, 11.22.

UNCLASSIFIED

Aconite.........$C_{13}H_{45}NO_{12}$....3.25, 5.80, 7.25, 7.87, 8.55, 9.18, 10.18, 11.05, 11.30.

Eserine.........$C_{15}H_2N_3O_2$......3.10, 5.85, 6.55, 8.00, 8.35, 8.92, 9.80, 90.50, 11.45.

TABLE II



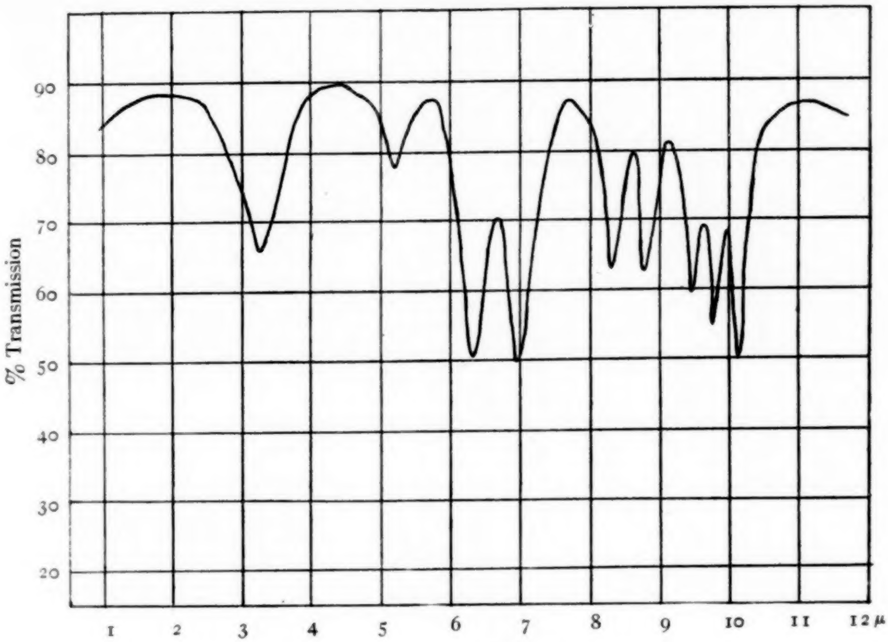


FIG. 1.—Pyridine

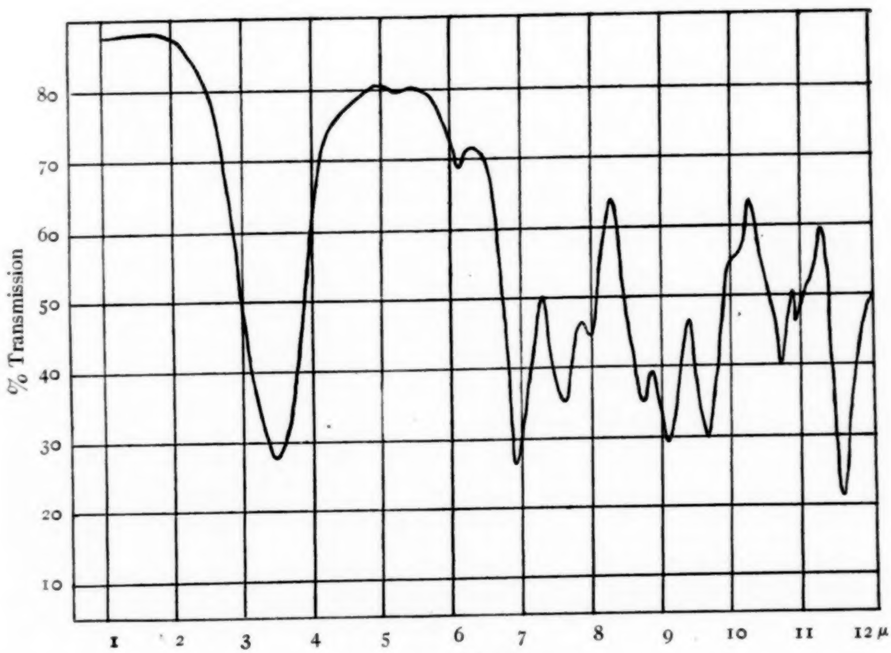


FIG. 2.—Piperdine

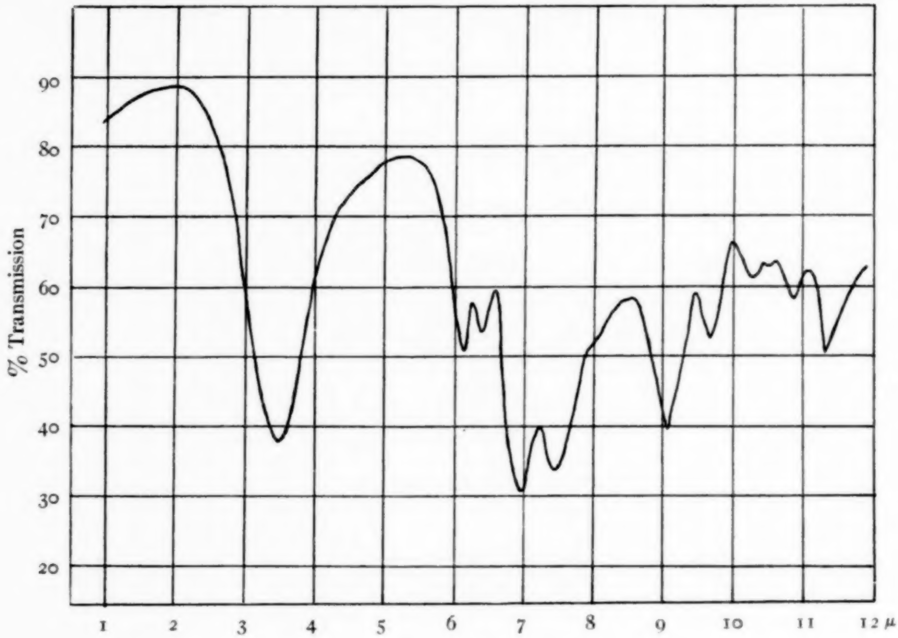


FIG. 3.—Coriine

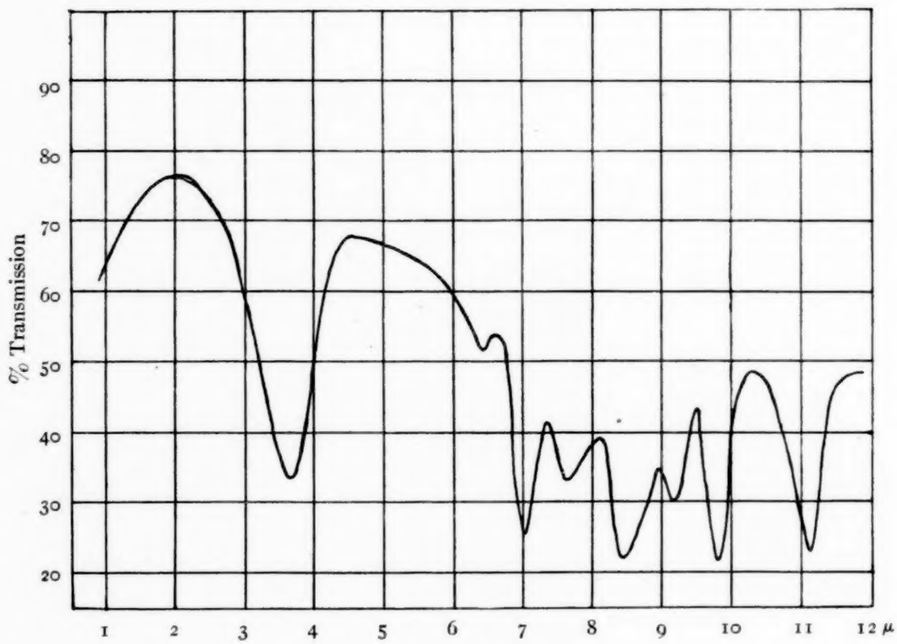


FIG. 4.—Nicotine

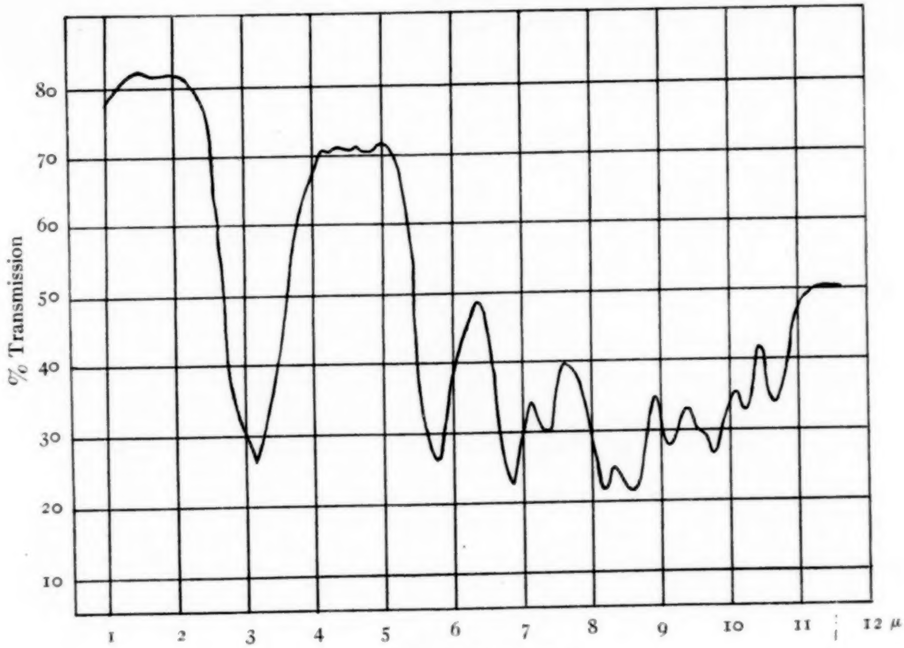


FIG. 5.—Pelocarpine

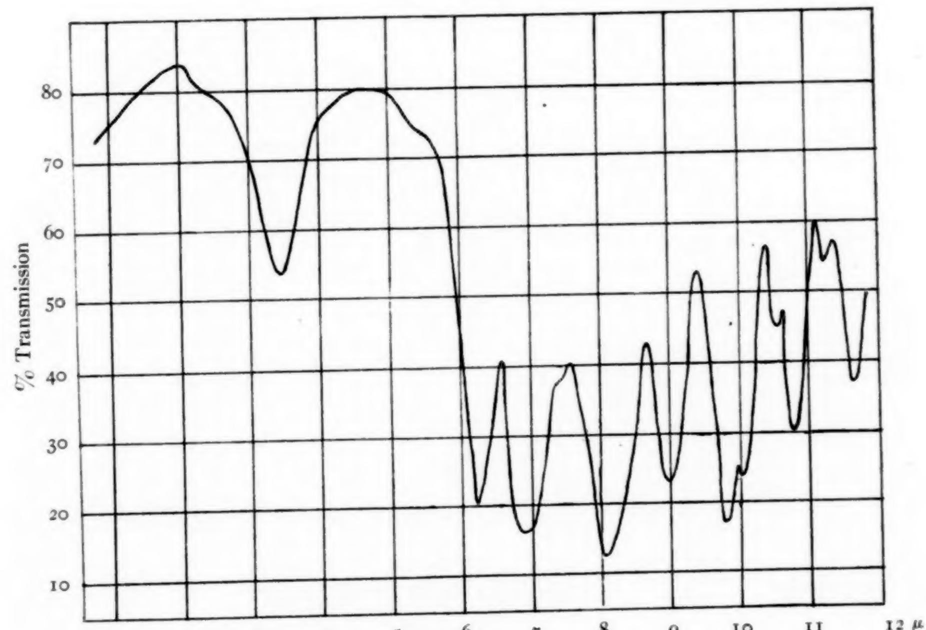


FIG. 6.—Piperine

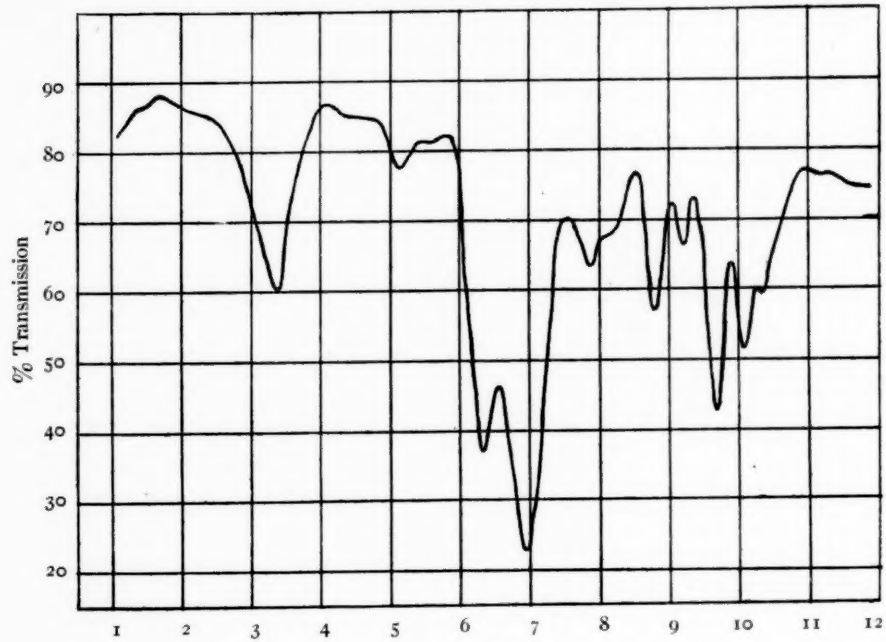


FIG. 7.—α-Picoline

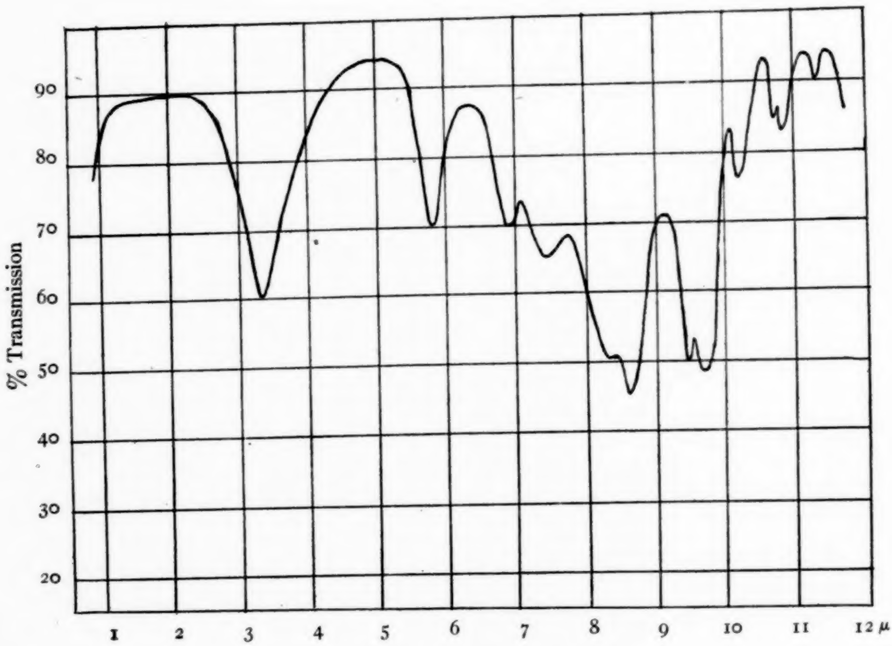


FIG. 8.—Atropine

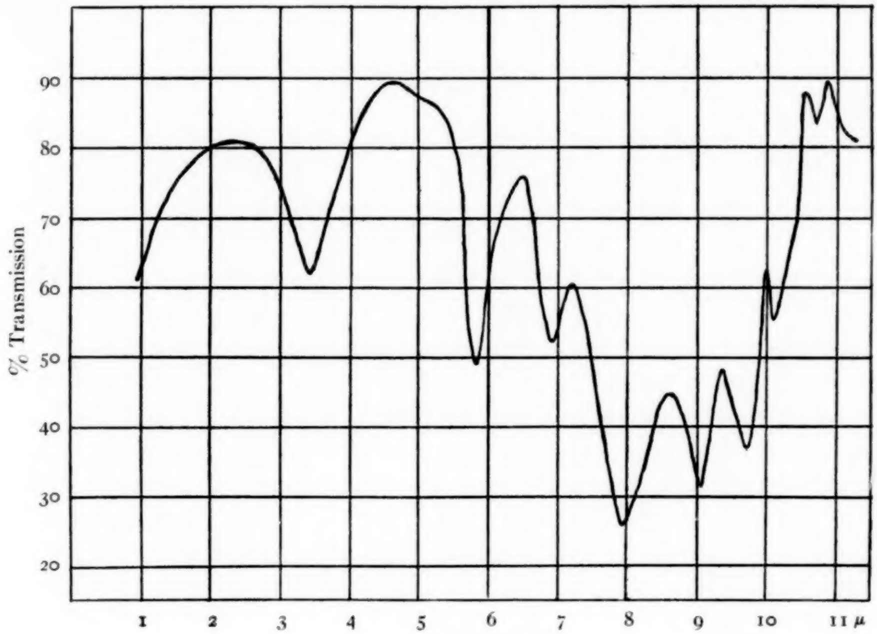


FIG. 9.—Cocaine

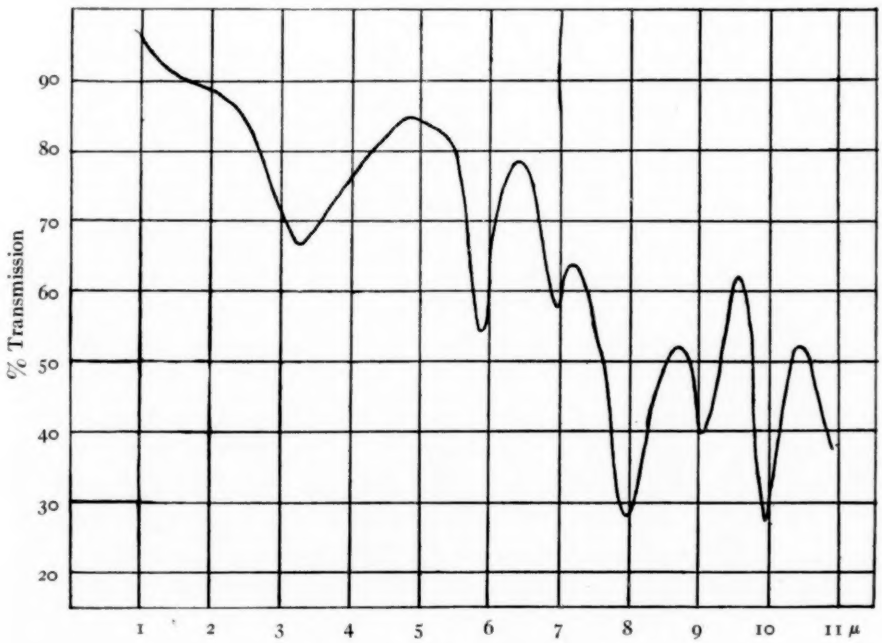


FIG. 10.—Cocaine hydrochloride

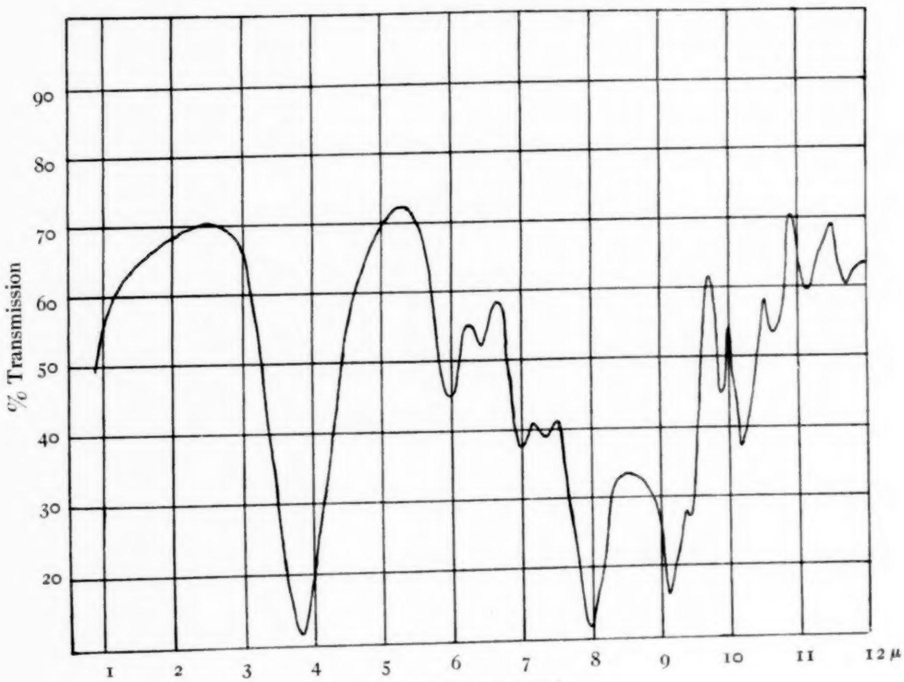


FIG. 11.—Beta eucaine

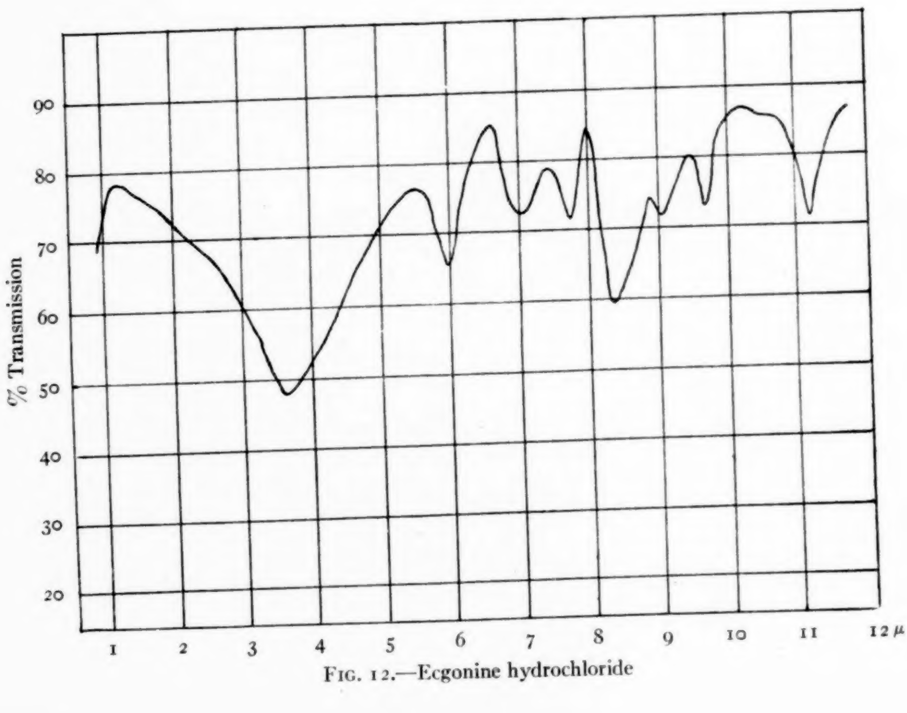


FIG. 12.—Ecgonine hydrochloride

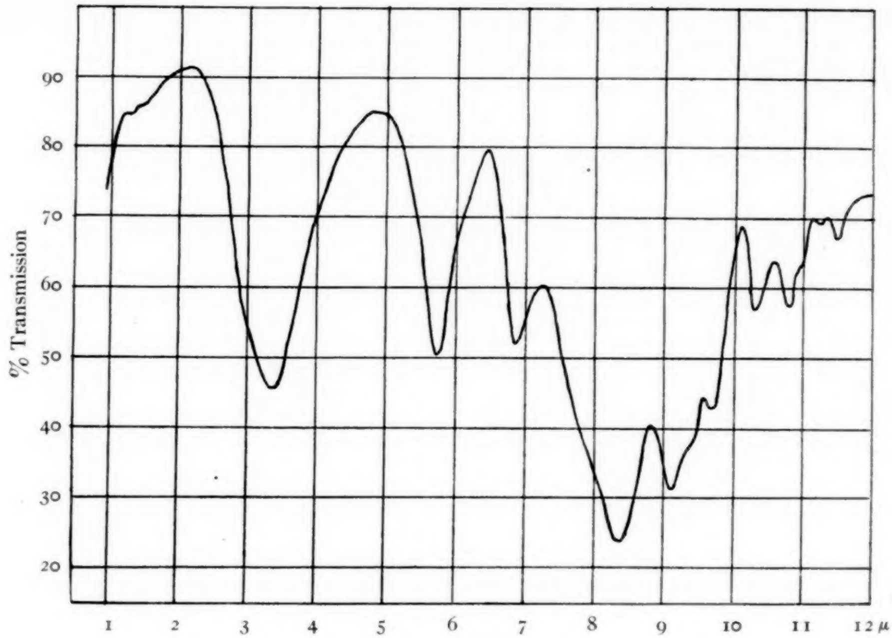


FIG. 13.—Homatropine

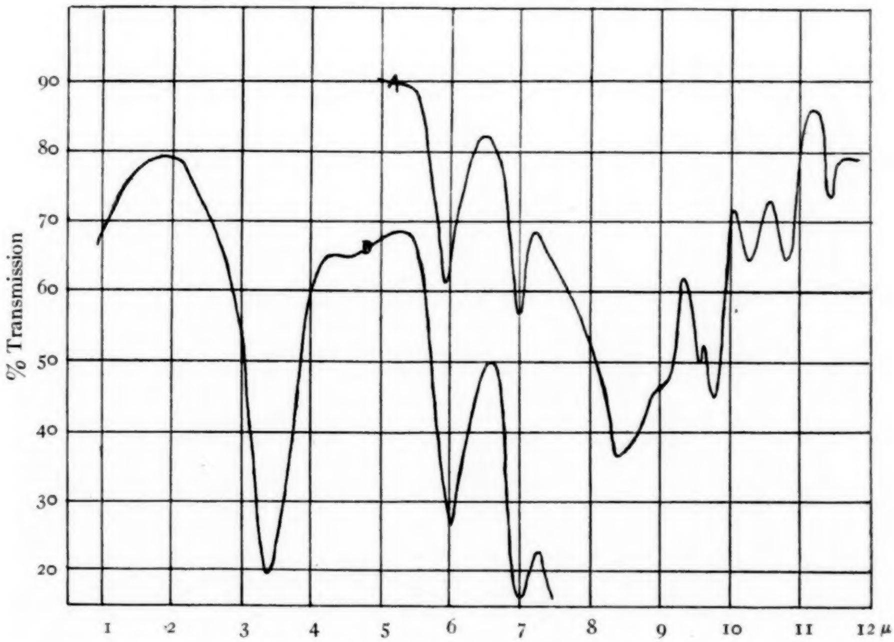


FIG. 14.—Belladonna

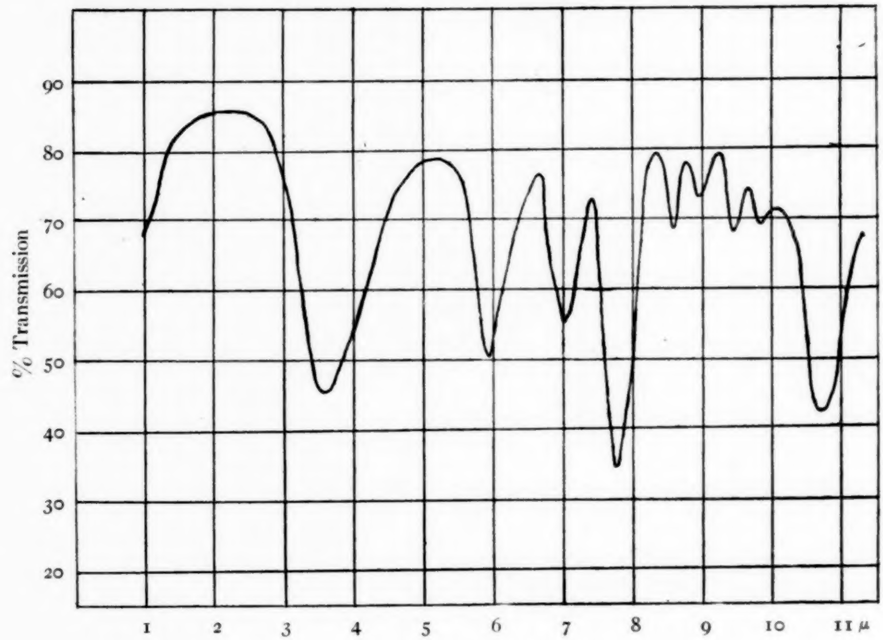


FIG. 15.—Benzoic acid

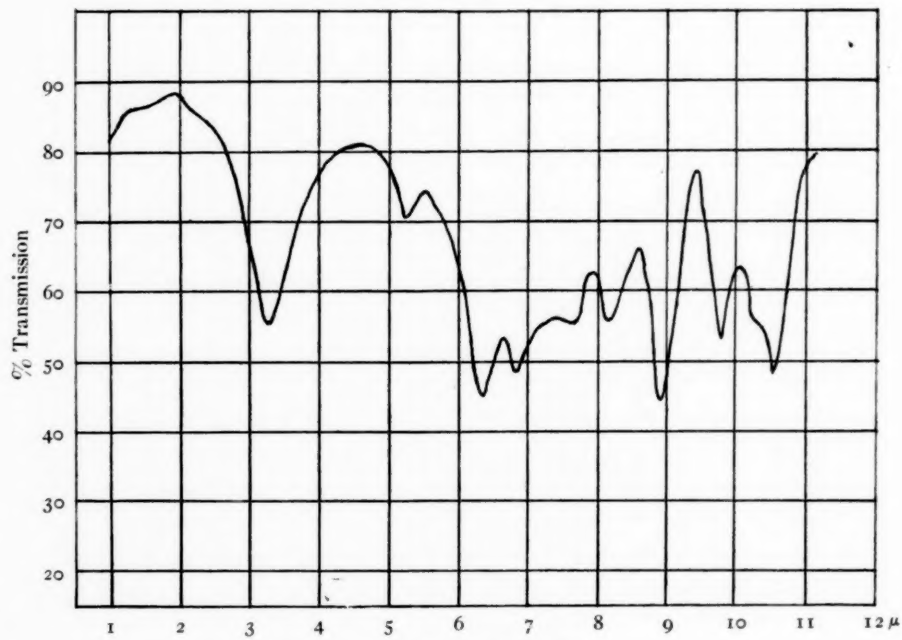


FIG. 16.—Quinoline

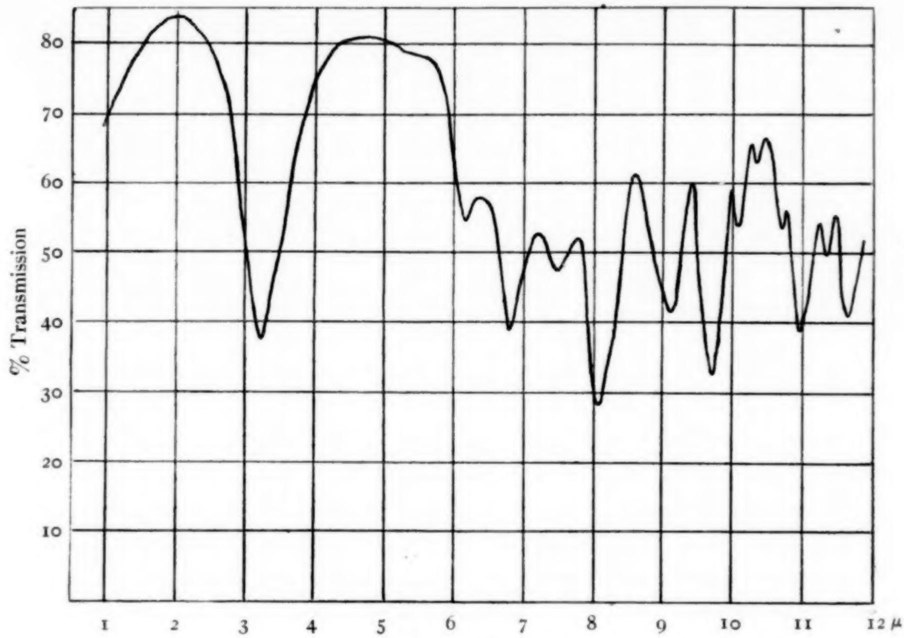


FIG. 17.—Quinine

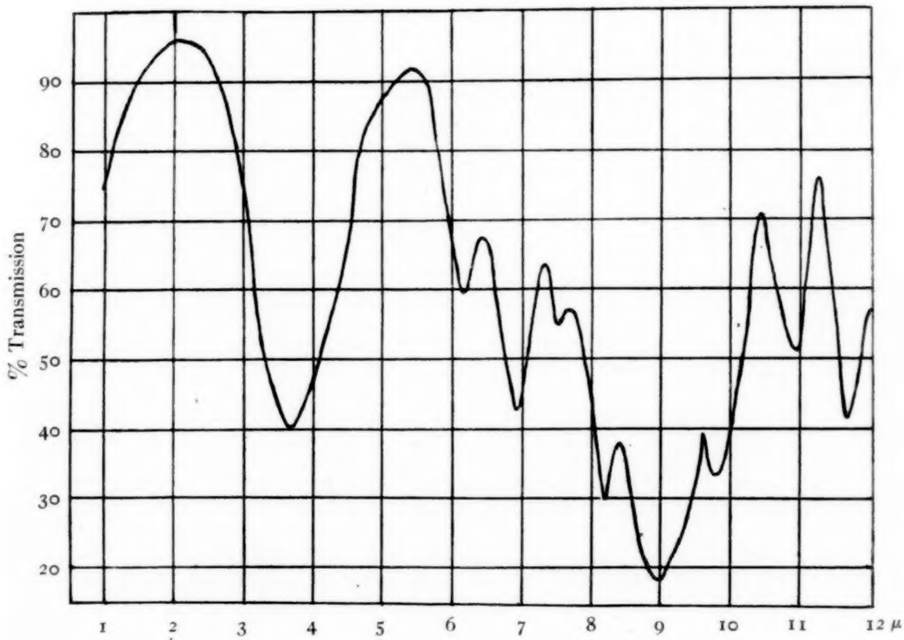


FIG. 18.—Quinine sulphate

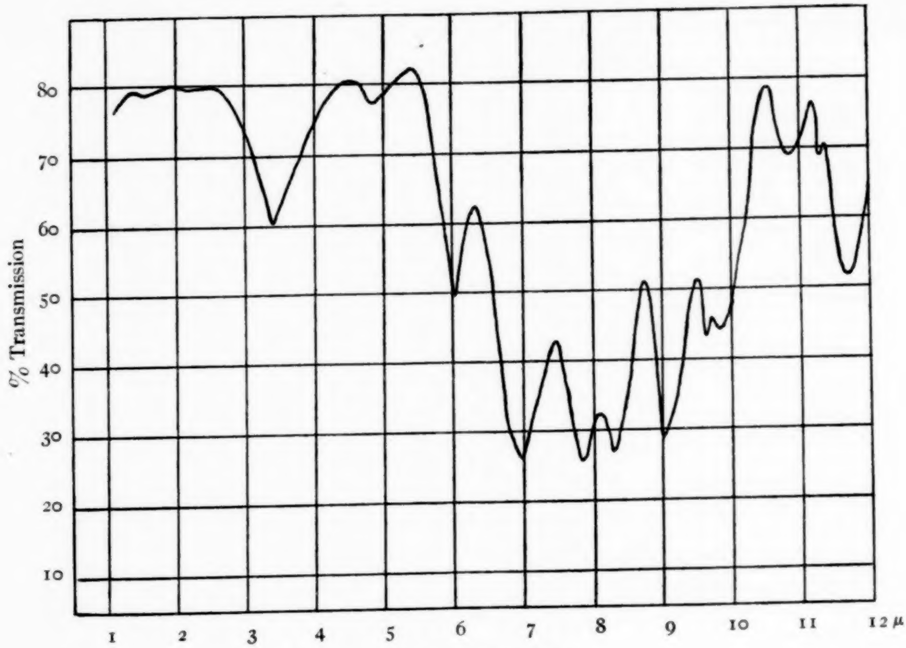


FIG. 19.—Brucine

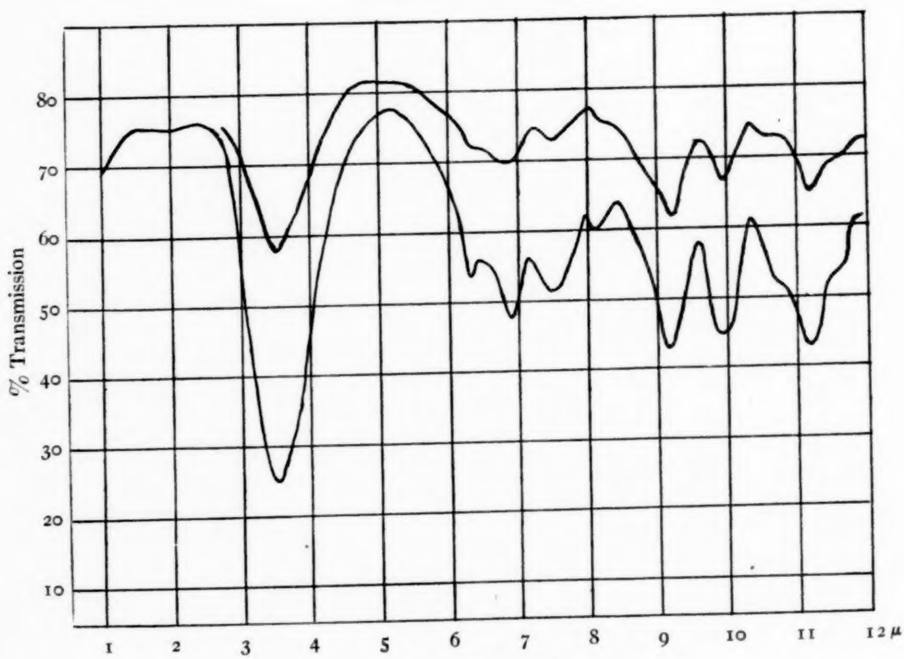


FIG. 20.—Chinconidine

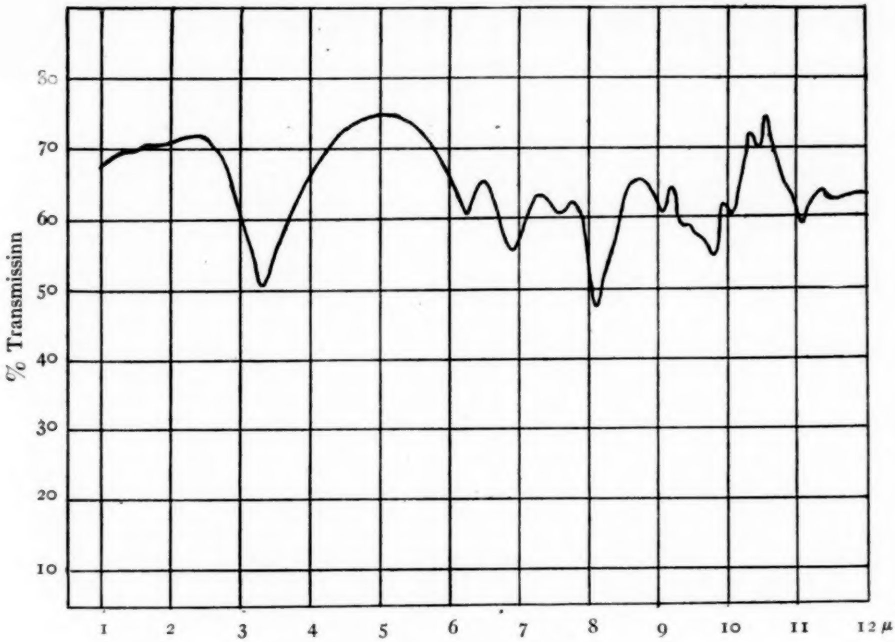


FIG. 21.—Quinidine

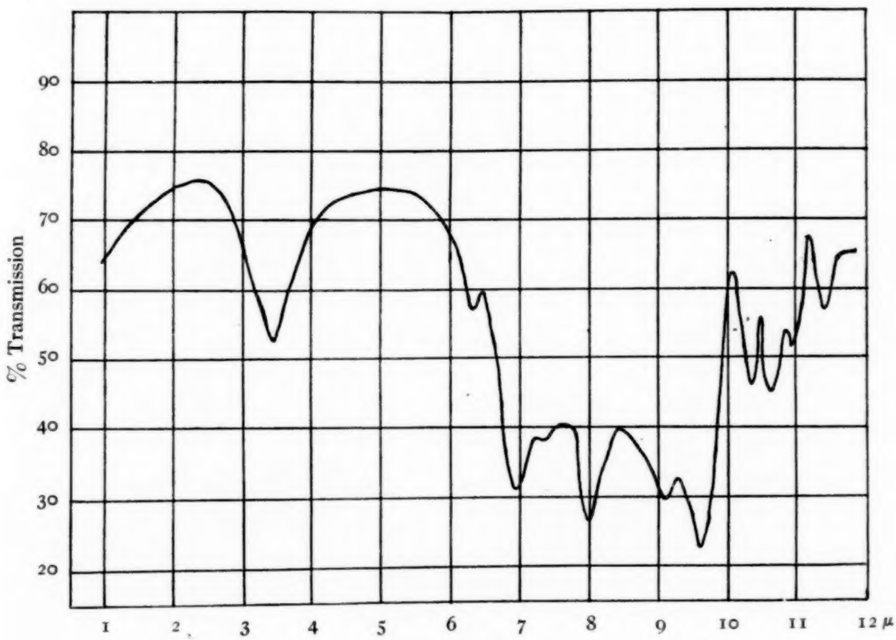


FIG. 22.—Codeine

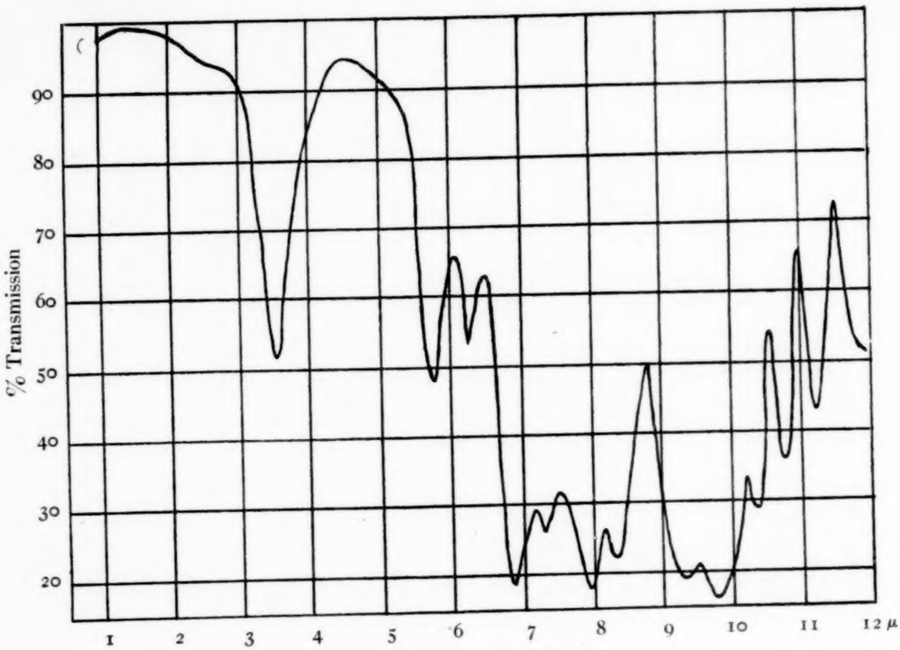


FIG. 23.—Narcotine

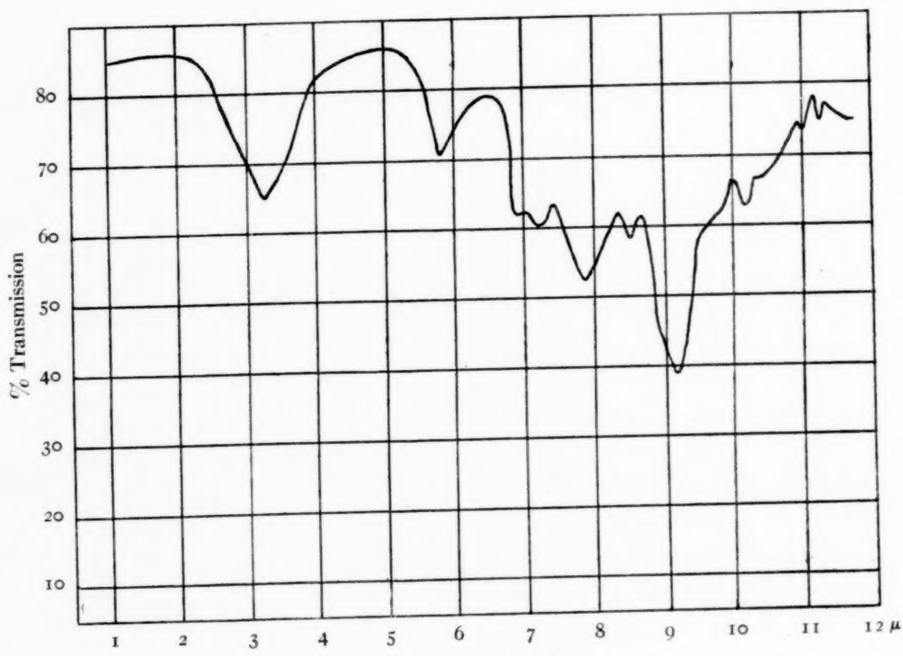


FIG. 24.—Aconitine

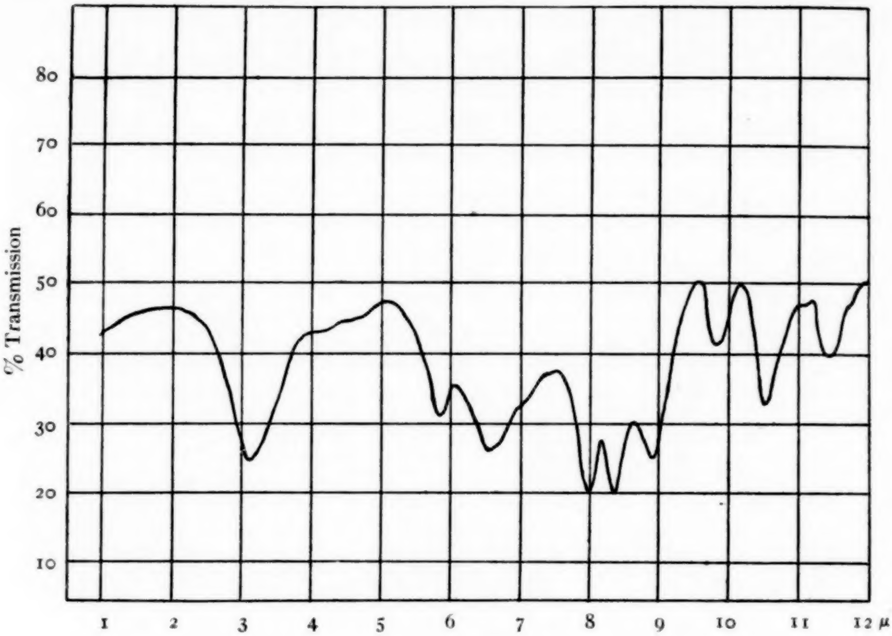


FIG. 25.—Eserine

Under the quinoline group was studied quinine sulphate to learn what relation might exist, if any, between the alkaloid and its salt. Quinine and its salts, which are numerous, would have formed an interesting group to study, but unfortunately most of the salts are of such a nature that it was impossible to put them in any transparent form before the slit of the spectrometer.

Of the isoquinoline group only two alkaloids were studied, namely codeine and narcotine. In general, the melting-points of this group are too high for them to melt without decomposition. A number of well known alkaloids such as caffeine and theine constitute this group.

Two alkaloids, aconitine and eserine of rather hazy grouping were studied. Little is known, comparatively speaking, of the chemistry of either of these alkaloids.

RESULTS

A reference to the accompanying curves will show the various absorption curves for the alkaloids studied. Table II was arranged

for the convenience of comparing the absorption spectra. It states the group, alkaloid, and the location of the absorption bands. A casual glance shows one that there are no identical spectra. Many of them are similar in appearance and a great many have bands in common. In comparing these spectra with spectra of other compounds obtained by other investigators, for example the work of Coblentz (*loc. cit.*), which contains over one hundred and fifty absorption spectra, one finds nothing identical in the way of spectra.

In general the spectra of the alkaloids show a large band between the limits $3.10\,\mu$ and $3.60\,\mu$. In the large majority of cases this band lies between the limits $3.25\,\mu$ and $3.50\,\mu$. In very few instances a band lies at the wave-length $3.43\,\mu$ which Coblentz attributes to the CH_2 or the CH_3 groups which in all of these alkaloids are quite prominent. The band at $3.43\,\mu$ attributed to the foregoing groupings might easily have been masked by the presence of groups which influence the absorption in that region.

All of the spectra show a band between the limits $6.80\,\mu$ and $7.05\,\mu$. The absorption in this region is in all probability due to the CH_2 or the CH_3 groups as shown by Coblentz, who places the band at $6.86\,\mu$. One finds again a characteristic absorption in the region of $9.75\,\mu$, the limits being $9.65\,\mu$ and $9.85\,\mu$. A band in this position is attributed to the C_6H_6 group, but it is difficult to see how this band may be attributed to the C_6H_6 group when this group is not shown chemically to be present.

Studying the groups separately one finds that they possess somewhat more individuality, yet nothing very striking is to be observed. The pyridine group possesses a large band in the region limited by the wave-lengths $3.15\,\mu$ and $3.60\,\mu$. Another region lies between the limits $6.10\,\mu$ and $6.40\,\mu$ with pilocarpine as the exception. Again one finds a region having the wider limits $6.85\,\mu$ and $7.05\,\mu$ and also a narrower region of limits $9.65\,\mu$ and $9.85\,\mu$.

The atropine group possesses a band in the region comprising the wave-lengths $3.10\,\mu$ and $3.80\,\mu$, a narrower region comprised between the wave-lengths $5.75\,\mu$ and $6.10\,\mu$. Two more regions having the limits $6.85\,\mu$ and $7.05\,\mu$ and $9.70\,\mu$ and $9.90\,\mu$ are present.

Homatropine appears to behave anomalously. Benzoic acid studied in connection with this group possesses the bands which are characteristic of this group, namely, the bands at 5.90 μ, 7.05 μ, and 9.80 μ. Benzoic acid is a derivative of benzene but shows only the band at 9.80 μ attributed to benzene.

The quinoline group possesses a number of regions where absorption is common. These regions have the following values: 3.25 μ to 3.50 μ, 6.00 μ to 6.35 μ, 6.80 μ to 6.95 μ, 7.45 μ to 7.65 μ, 8.10 μ to 8.15 μ, 8.90 μ to 9.15 μ, and finally 9.75 μ to 9.95 μ. Brucine forms an exception to the above statement in two instances. Quinine sulphate has only three bands in common with quinine from which it is derived.

Of the isoquinoline group little may be said, for not many members of the group have been studied. Of the two unclassified alkaloids it is unsafe to make predictions as to grouping. They may be members of groups not studied.

In a few instances water of crystallization was present, but in no instance was the band attributed to water of crystallization at 3 μ present. Undoubtedly the presence of the band was masked by the presence of other free periods whose frequencies were not far removed from that at 3 μ.

On the whole, little information can be obtained from the groups studied concerning the relation of infra-red absorption to molecular grouping. Our knowledge of the mechanism of absorption is very meager and it may be that we are working in the dark with reference to the relation of absorption to molecular grouping. However, until the problem is put upon a more firm theoretical basis, our only resource is the statistical method which ultimately will aid the solution of the problem of absorption.

University of North Dakota
October 1913

Minor Contributions and Notes

SPECTROSCOPIC BINARIES UNDER INVESTIGATION AT DIFFERENT INSTITUTIONS

The following letter was recently sent out to the principal institutions at which spectrographic observations are now being made.

YERKES OBSERVATORY
WILLIAMS BAY, WISCONSIN
September 2, 1913

DEAR SIR:

It seems desirable to collect and print in the *Astrophysical Journal* statements from the different observatories as to spectrographic binaries which are under special observation at the several institutions with a view to a determination of the orbits. This was done in 1908 (Vol. **27**, p. 161) and presumably prevented unnecessary duplication of effort both in securing spectrograms and in measuring them. It also serves a purpose in indicating the present state of research in this direction. Will you therefore be kind enough to communicate to me at your earliest convenience such a statement, in form for publication, regarding the work at the ——— observatory?

Very truly yours,
EDWIN B. FROST

The replies that have been received follow, translated when not in English, and in some cases somewhat abridged. Some of the letters contain information not strictly pertaining to spectroscopic binaries, but of interest to those engaged in spectrographic work.

ALLEGHENY OBSERVATORY OF THE
UNIVERSITY OF PITTSBURGH
September 8, 1913

Here is the list of spectroscopic binaries that we are at present observing, with the approximate Right Ascensions:

1	*Persei*	1^h46^m	*59*	*d Serpentis*	18^h22^m
RZ	*Cassiopeiae*	2 40	*43*	*φ Draconis*	18 22
B.D.	*−1°943*	5 29	*11*	*δ¹ Lyrae*	18 50
19	*Lyncis*	7 16	*1*	*Vulpeculae*	19 12
18	*Ursae Majoris*	9 10	*44*	*σ Aquilae*	19 35
55	*Ursae Majoris*	11 14		*Boss 5070*	19 47
95	*Leonis*	11 51		*Boss 5113*	19 54
12	*Comae*	12 17	*30*	*Cephei*	22 36
7	*δ Scorpii*	15 55	*12*	*Lacertae*	22 38
10	*λ Ophiuchi*	16 26	*16*	*Lacertae*	22 52
108	*Herculis*	18 18			

In addition, we have finished observing the following stars, but the results have not yet been published:

4	*g Persei*	1^h55^m	*14*	*ι Coronae*	15^h57^m
26	*β Persei*	3 01		*U Ophiuchi*	17 12
45	*ε Persei*	3 51	*111*	*Herculis*	18 43
35	*λ Tauri*	3 55	*18*	*Aquilae*	19 02
15	*S Monocerotis*	6 36	*30*	*δ Aquilae*	19 20
	R Canis Majoris	7 15	*26*	*θ Pegasi*	22 05
B.D.	$+3°2867$	14 07	*6*	*Lacertae*	22 26
B.D.	$+6°2875$	14 19	*1*	*o Andromedae*	22 57
25	*Serpentis*	15 41			

We have abandoned *43 θ² Orionis* (5^h30^m) at the request of the Ottawa observers; and we have also abandoned *41 θ¹ Orionis* (5^h30^m) on account of the character of the lines in its spectrum.

F. SCHLESINGER

DETROIT OBSERVATORY
UNIVERSITY OF MICHIGAN
ANN ARBOR, September 13, 1913

The following list includes those announced binary stars on which the spectroscopic work at the Detroit Observatory has progressed far enough to justify an announcement. The order in which these stars are arranged in the list will give some indication of the degree of advancement of the work. Those named first have received the most attention.

14	*γ Lyrae*	18^h55^m	*80*	*g Ursae Majoris*	13^h21^m
	ζ¹ Ursae Majoris	13 20	*20*	*Tauri*	3 40
	ζ² Ursae Majoris	13 20	*47*	*ρ Leonis*	10 27
8	*β Cephei*	21 27	*50*	*α Cygni*	20 38
10	*β Lyrae*	18 46	*55*	*α Ophiuchi*	17 30

R. H. CURTISS

DOMINION ASTRONOMICAL OBSERVATORY
OTTAWA, CANADA
September 17, 1913

In reply to your circular letter of the 2d inst., I would say that the present condition of the orbital determination of spectroscopic binaries is not very satisfactory.

The process of selection of binaries for investigation was to choose first of all those with a high range of velocity and with good or moderately good spectra. Consequently the binaries now available for investigation consist practically wholly of stars with poor spectra or with a low range of velocity or with both of these drawbacks. I am convinced that all workers in this line of research, especially those like ourselves with small aperture, have felt that the binaries which offer any prospect of yielding satisfactory orbits are very few indeed.

We at Ottawa have made a large number of spectra of several binaries, in one or two cases more than a hundred plates of a star, without being able to obtain a period, and it is very likely that several stars on our present list will prove equally unsatisfactory.

For convenience the binaries under investigation at Ottawa are tabulated into different groups.

SPECTROSCOPIC BINARIES WITH LARGE NUMBER OF PLATES OBTAINED

51	*μ Persei*	4^h08^m	*47*	*ρ Leonis*	10^h27^m
66	*ν Tauri*	4 18	*4*	*γ Corvi*	12 11
86	*ρ Tauri*	4 28	*23*	*Comae*	12 30
20	*τ Orionis*	5 13	*B.A.C.*	*5890*	17 19
136	*Tauri*	5 47	*17*	*ι Andromedae*	23 33
18	*ν Geminorum*	6 23			

SPECTROSCOPIC BINARIES RECENTLY ADDED, ONLY FEW PLATES OBTAINED

15	*κ Cassiopeiae*	0^h27^m	*107*	*μ Virginis*	14^h38^m
34	*ζ Andromedae*	0 42	*13*	*δ Serpentis*	15 30
8	*δ Trianguli*	2 11	*67*	*Ophiuchi*	17 56
113	*α Piscium*	1 57	*68*	*Ophiuchi*	17 57
83	*φ Geminorum*	7 47	*41*	*ι Aquilae*	19 32
65	*α Cancri*	8 53	*12*	*Lacertae*	22 37

SPECTROSCOPIC BINARIES PROPOSED FOR INVESTIGATION

43	*ω Cassiopeiae*	1^h48^m	*50*	*α Cygni*	20^h38^m
25	*χ Aurigae*	5 26	*30*	*Cephei*	22 36
B.D.	$-1°943$	5 28			

SPECTROSCOPIC BINARIES, WORK DISCONTINUED, INABILITY TO OBTAIN PERIOD

77	*σ Leonis*	11^h16^m	*58*	*ν Cygni*	20^h53^m
72	*Ophiuchi*	18 03	*48*	*γ Aquarii*	22 16
17	*ζ Aquilae*	19 01			

The measures of the stars in the last list will be published in due course, enabling an approximation to the velocity of the system to be obtained, and giving opportunity to others to attempt a determination of the orbit.

J. S. PLASKETT

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE, MASS., September 5, 1913

Your letter of September 2, addressed to Professor Pickering, who is still in Europe, is received. I think the statement made in 1907 by Professor

Pickering,[1] as given in the *Astrophysical Journal*, **27**, 162, still holds true, but I will call his attention to your letter on his return, the latter part of this month.

S. I. Bailey

Königliche Sternwarte
Bonn, September 26, 1913

In reply to your inquiry of September 2, I would state that at present no spectroscopic binaries are under special observation with a view to the determination of their orbits. But in the general series of observations of stars of type F to M there are doubtless contained isolated observations of a large number of spectroscopic binaries. I give these stars, with the number of plates obtained. These spectrograms are measured and reduced, and results will be gladly placed at the disposal of those interested.

31	δ *Andromedae*	(3)	0^h34^m		A *Boötis*	(3)	14^h14^m
34	ζ *Andromedae*	(3)	0 42	3	β *Coronae*	(5)	15 24
38	η *Andromedae*	(3)	0 52	13	θ *Draconis*	(3)	16 00
43	β *Andromedae*	(4)	1 04	44	η *Herculis*	(3)	16 39
85	φ *Piscium*	(3)	1 08	22	ε *Ursae Minoris*	(8)	16 56
65	ξ¹ *Ceti*	(2)	2 08	47	o *Draconis*	(2)	18 50
8	δ *Trianguli*	(3)	2 11	113	*Herculis*	(4)	18 51
12	*Persei*	(3)	2 36	6	*Hev.* β *Scuti*	(2)	18 42
18	τ *Persei*	(4)	2 47	60	τ *Draconis*	(3)	19 17
1	o *Tauri*	(3)	3 19	12	φ *Cygni*	(5)	19 35
51	μ *Persei*	(3)	4 08	7	δ *Sagittae*	(3)	19 43
47	*Tauri*	(3)	4 08	55	η *Aquilae*	(2)	19 47
88	*d Tauri*	(7)	4 30	63	ε *Draconis*	(3)	19 49
8	ζ *Aurigae*	(3)	4 55	32	*Cygni*	(4)	20 12
16	*Aurigae*	(5)	5 12	71	*l Aquilae*	(3)	20 32
58	α *Orionis*	(3)	5 50	6	β *Delphini*	(3)	20 33
1	*Geminorum*	(3)	5 58	62	ξ *Cygni*	(4)	21 01
7	η *Geminorum*	(4)	6 09	10	κ *Pegasi*	(4)	21 40
43	ζ *Geminorum*	(2)	6 58	21	ζ *Cephei*	(2)	22 07
4	γ *Canis Minoris*	(3)	7 23	24	*Cephei*	(3)	22 08
75	σ *Geminorum*	(4)	7 37		$+38°4711$	(3)	22 10
11	ε *Hydrae*	(4)	8 41	27	δ *Cephei*	(3)	22 25
53	ξ *Ursae Majoris*	(5)	11 13	33	π *Cephei*	(4)	23 05
5	*Canum Venaticorum*	(3)	12 19	70	*q Pegasi*	(3)	23 24
12	*d Boötis*	(3)	14 06				

F. Küstner

[1] "The only spectroscopic binaries likely to be investigated at the Harvard College Observatory are those of Class A, in which both components are bright. They have been photographed here for many years, and the plates obtained will permit a very precise determination of their periods. No investigations of spectroscopic binaries of Class B, in which only one component is bright, are contemplated here at present.—Edward C. Pickering."

Under date February 9, 1914, Professor Pickering writes: "Professor Bailey's letter represents my present views."

KGL. ASTROPHYSIKALISCHES OBSERVATORIUM
POTSDAM, October 21, 1913

At the request of Director Schwarzschild, I advise you as follows regarding the spectroscopic binaries under observation at Potsdam.

Of the observations obtained with Spectrograph IV attached to the 32.5 cm refractor, there are yet unpublished those of *7 ε Aurigae* (about 180 plates), *50 α Cygni* (about 180 plates), and *24 γ Geminorum* (about 70 plates). The radial velocity of *7 ε Aurigae* cannot be represented by a simple elliptical orbital motion and it seems highly probable that the same is true of *50 α Cygni* and of *24 γ Geminorum*. I shall continue the observations of these three stars.

With Spectrograph III, attached to the 80 cm refractor, certain spectroscopic binaries, among other objects, have been observed by Dr. Münch and myself in the course of the past year in order to test the efficiency of the spectrograph in its new form (with short camera). The stars are *63 Tauri, 108 Herculis,* and *111 Herculis.* A preliminary orbit of *63 Tauri* has been completed by Dr. Jantsen, and sufficient material is available for a similar orbit of *108 Herculis,* upon which I am now at work. Plates of *111 Herculis* have not yet been measured.

Observations with the 80 cm refractor are at present interrupted, as the figure of the objective is receiving correction by Steinheil. The spectrograph is meanwhile being reconstructed. A new program cannot be laid out until these two operations are completed.

H. LUDENDORFF

LICK OBSERVATORY
MOUNT HAMILTON, CALIFORNIA
September 26, 1913

The following is the list of spectroscopic binaries upon which members of our staff are now working:

	U Ophiuchi	17^h12^m		*h Centauri*	13^h48^m
	X Cygni	20 40	*10*	*κ Pegasi*	21 40
46	*υ Sagittarii*	19 16	*12*	*Persei*	2 36
41	*$υ_4$ Eridani*	4 14	*10*	*α Canis Minoris*	7 34
	H Velorum	8 53	*1*	*α Ursae Minoris*	1 23

W. W. CAMPBELL

MOUNT WILSON SOLAR OBSERVATORY
September 26, 1913

At present we are planning no work at Mount Wilson on the determination of the orbits of spectroscopic binaries. Our observational program consists almost wholly of stars fainter than the sixth magnitude, and comparatively few spectroscopic binaries as faint as this are known. It is possible that we may make a few observations of some of the fainter Algol variables, such as *RW Tauri*, but apart from this we have no plans in view for work of this character.

W. S. ADAMS

PARIS, September 28, 1913

The sky at Paris is continually disturbed in summer, as well as in winter, and does not permit us to undertake researches requiring continuity in the observations. Evenings without clouds are very few, and still more rare are those in which the images are good. It is for this reason that I have eliminated spectroscopic binaries from our program. I am observing the list of bright stars given in the *Annuaire du Bureau des Longitudes*, with the exception of those which are given as double in Campbell's *Catalogue* which appeared in 1911. Accordingly, the letter which you recently wrote me does not bear on the observations at Paris.

M. HAMY

PULKOWA
October 3, 1913

On account of climatic conditions, and particularly on account of the unfavorable arrangement of our dome, I am not in a position to observe objects according to my own choice. My program is to observe everything which is accessible with the weather we have. If I am able to repeat an observation after a few days, I obtain material for discussion; otherwise, the observations are lost and I have to begin over again. Therefore if I were to refrain from observing an object which is under observation elsewhere, I should practically have to cease observations entirely.

I have selected a number of stars not fainter than 3.5 mag., from Campbell's *Catalogue*, as well as some which have special interest for me.

21	α *Andromedae*	0^h03^m	77	ϵ *Ursae Majoris*	12^h50^m
33	α *Persei*	3 17	27	γ *Boötis*	14 28
7	ϵ *Aurigae*	4 55	36	ϵ *Boötis*	14 41
34	β *Aurigae*	5 52	40	ζ *Herculis*	16 38
43	ζ *Geminorum*	6 58	14	γ *Lyrae*	18 55
66	α^1 *Geminorum*	7 28	55	η *Aquilae*	19 47
41	γ^1 *Leonis*	10 14	50	α *Cygni*	20 38
41	γ^2 *Leonis*	10 14	53	ϵ *Cygni*	20 42
29	γ^1 *Virginis*	12 37	53	β *Pegasi*	22 59
29	γ^2 *Virginis*	12 37		*Saturn*	
12	α *Canum Venaticorum*	12 51		*Venus*	

and the standard velocity stars.

Also, for instrumental purposes:

3	α *Lyrae*	18^h34^m

and stars for a scale of spectral type:

4	β *Trianguli*	2^h04^m	58	α *Orionis*	5^h50^m
44	ζ *Persei*	3 48	10	α *Canis Minoris*	7 34
87	α *Tauri*	4 30	78	β *Geminorum*	7 39
24	γ *Orionis*	5 20	16	α *Boötis*	14 11
46	ϵ *Orionis*	5 31	64	α^1 *Herculis*	17 10

A. BELOPOLSKY

ROYAL OBSERVATORY
CAPE OF GOOD HOPE
October 3, 1913

In reply to your inquiry dated September 2, we have no observations specially made here for the purpose of investigating spectroscopic binaries, but I inclose for your information a list of stars included in our current working-list of which one or more spectrograms have been obtained.

S. S. HOUGH

CAPE OF GOOD HOPE

	ε *Phoenicis*	*H.P.*	*821 Eridani*		*I Puppis*
8	ι *Ceti*		α *Caeli*		ε *Puppis*
	ζ *Toucani*	3	π^3 *Orionis*		ζ *Volantis*
	β *Hydri*		γ *Caeli* (du.)		ξ *Puppis* (var.?)
	α *Phoenicis*	2	ε *Leporis*		*a Puppis*
	β^2 *Toucani*	19	β *Orionis*		*j Puppis*
31	δ *Andromedae*	9	β *Leporis*		ρ *Puppis*
16	β *Ceti*		ε *Columbae*		h^2 *Puppis*
63	δ *Piscium*	11	α *Leporis*	17	β *Cancri*
	β *Phoenicis*	40	ϕ^2 *Orionis*		ε *Carinae*
31	η *Ceti*		β *Doradus*		θ *Chamael.*
45	θ *Ceti*	13	γ *Leporis*		β *Volantis*
	γ *Phoenicis*	15	δ *Leporis*		*e Velorum*
99	η *Piscium*		β *Columbae*		β *Pyxidis*
	δ *Phoenicis*		γ *Pictoris*		*d Velorum*
52	τ *Ceti*	58	α *Orionis*	11	ε *Hydrae*
	χ *Eridani*	16	η *Leporis*		γ *Pyxidis*
78	ν *Ceti*	*S.H.P.*	*1319 Doradus*	16	ζ *Hydrae*
13	α *Arietis*		η *Columbae*		*w Velorum*
68	ο *Ceti*	7	η *Geminorum*		*c Velorum*
	ι *Eridani*		κ *Columbae*		λ *Velorum*
87	μ *Ceti*	13	μ *Geminorum*		*g Carinae*
	β *Fornacis*		δ *Columbae*		*G Carinae*
3	η *Eridani*		α *Carinae*		ι *Carinae*
92	α *Ceti*	24	γ *Geminorum*	30	α *Hydrae*
	α *Fornacis*	27	ε *Geminorum*		ψ *Velorum*
16	τ^4 *Eridani*	9	α *Canis Majoris*		*N Velorum*
	e Eridani		α *Pictoris*		*M Velorum*
1	ο *Tauri*		τ *Puppis* (var.)	35	ι *Hydrae*
18	ε *Eridani*		*A Carinae* (var.)	14	ο *Leonis* (var.)
	y Eridani	16	o^1 *Canis Majoris*	17	ε *Leonis*
27	τ^6 *Eridani*	21	ε *Canis Majoris*		υ *Carinae* (du.)
	β *Reticuli*		σ *Canis Majoris*	24	μ *Leonis*
	g Eridani	43	ζ *Geminorum* (var.)		*m Velorum*
	γ *Hydri*	25	δ *Canis Majoris*	41	λ *Hydrae*
34	γ *Eridani*		γ^1 *Volantis*		*q Carinae*
	δ *Reticuli*		*J Puppis*	41	γ *Leonis* (du.)

CAPE OF GOOD HOPE—*Continued*

	α *Horlogii*
	α *Reticuli*
	γ *Doradus*
	δ *Tauri*
	d Eridani
77	θ^1 *Tauri*
	υ^1 *Eridani*
87	α *Tauri*
	υ^2 *Eridani*
H.P. 812	*Eridani*
12	δ *Crateris*
78	ι *Leonis*
	ξ *Hydrae*
	λ *Muscae*
S.H.P. 3966	*Centauri*
5	β *Virginis*
9	ο *Virginis*
	η *Crucis*
1	α *Corvi*
	p Velorum
2	ε *Corvi*
	ε *Muscae*
	ε *Crucis*
	γ *Crucis*
8	η *Corvi*
9	β *Corvi*
29	γ *Virginis* (du.)
	e Centauri
43	δ *Virginis*
	δ *Muscae*
	ε *Virginis*
H.P. 2232	*Com. Ber.*
46	γ *Hydrae*
	m Centauri
	d Centauri
	i Centauri
	g Centauri
5	υ *Boötis*
8	η *Boötis* (var.)
	υ^2 *Centauri*
49	π *Hydrae*
5	θ *Centauri*
	δ *Octantis*
16	α *Boötis*
	τ^2 *Lupi*
	α^2 *Centauri*
	π *Puppis*
	δ *Volantis*
60	ι *Geminorum*
	σ *Puppis*
H.P. 1431	*Puppis*
10	α *Canis Minoris*
H.P. 1452	*Monocerotis*
75	σ *Geminorum*
77	κ *Geminorum*
78	β *Geminorum*
3	β *Coronae*
	ε *Trianguli*
38	γ *Librae*
	ν *Librae*
	ω *Lupi*
	ψ^1 *Lupi*
	g Lupi
24	α *Serpentis*
35	κ *Serpentis*
41	γ *Serpentis*
	ξ *Scorpii*
	δ *Trianguli Australis*
1	δ *Ophiuchi*
	γ^2 *Normae*
2	ε *Ophiuchi*
	γ *Apodis*
21	α *Scorpii*
20	γ *Herculis*
	H Scorpii
	α *Trianguli Australis*
	η *Arae*
26	ε *Scorpii*
	ζ *Arae*
27	, *Herculis*
	η *Scorpii*
27	κ *Ophiuchi*
64	α *Herculis*
	β *Arae*
	Q Scorpii
55	ξ *Serpentis*
60	β *Ophiuchi*
	ι *Scorpii*
	G Scorpii
3	υ *Ophiuchi*
S 3308	*Velorum*
42	μ *Hydrae*
	I Carinae
	α *Antliae*
	s Carinae
	μ *Velorum*
	υ *Hydrae*
	μ *Carinae*
7	α *Crateris*
	χ *Carinae*
39	ο *Sagittarii*
40	τ *Sagittarii*
	δ *Coronae Australis*
	β *Coronae Australis*
41	π *Sagittarii*
	β^2 *Sagittarii*
50	γ *Aquilae*
55	η *Aquilae* (var.)
	ι *Sagittarii*
60	β *Aquilae*
	δ *Pavonis*
	α^1 *Capricorni*
	α^2 *Capricorni* (var.?)
	β *Capricorni* (var.)
	α *Indi*
6	β *Delphini*
	ψ *Capricorni*
12	γ *Delphini*
	β *Indi*
8	α *Equulei*
	γ *Pavonis*
	ζ *Capricorni*
	b Capricorni
22	β *Aquarii*
	ν *Octantis*
	γ *Capricorni*
8	ε *Pegasi*
34	α *Aquarii*
	α *Toucani*
	δ^1 *Gruis*
	β *Gruis*
46	ξ *Pegasi*
	τ *Aquarii*
73	λ *Aquarii*
	δ *Piscis Australis*

CAPE OF GOOD HOPE—*Continued*

	α^1 *Centauri*		γ^2 *Sagittarii*		α *Piscis Australis*
	α *Circini* (du.)	*70*	*Ophiuchi* (Bi)		ζ *Gruis*
	α *Apodis*		η *Sagittarii* (du.)		c^2 *Aquarii*
	c^1 *Centauri*	*19*	δ *Sagittarii*	*6*	γ *Piscium*
36	ϵ *Bootis*	*58*	η *Serpentis* (var.?)		γ *Sculptoris*
	γ *Scorpii* }		ζ *Telescopii*		b^1 *Aquarii*
20	σ *Librae* }	*22*	λ *Sagittarii*	*28*	ω *Piscium*
	ζ *Lupi*		ζ *Pavonis*		ι *Gruis* (var.)
	ϕ^1 *Lupi*	*37*	ξ^2 *Sagittarii*		

UNIVERSITY OBSERVATORY
VIENNA, October 3, 1913

At the conclusion of the year 1912 a single-prism spectrograph was mounted in connection with the Rothschild coudé telescope of the Vienna Observatory. The spectrograph hangs on a track freely in the observing room and is not connected with the telescope, even during observations. On account of its constant position the instrument may be designated as perfectly free from flexure. The focal length of the collimator is 1007 mm, and the two cameras have focal lengths of respectively 300 mm and 580 mm. The instrument has been in use since February 1913, when the adjustments were completed. The observing program for it includes the stars, about 200 in number, to the 6th magnitude, which are contained in the zone from the north pole to +60° Dec., and of which the radial velocities have not been published in the Bulletins of the Lick Observatory, Nos. 195, 211, 212, 214, and 229. I expect also to undertake the determination of the orbits of spectroscopic binaries which may be discovered in this zone.

ADOLF HNATEK

YERKES OBSERVATORY
WILLIAMS BAY, WIS.
February 4, 1914

The following spectroscopic binaries, all of which were originally or independently detected here, are under observation or measurement with a view to the determination of the orbit, when and if the materials shall be adequate for the purpose. The accumulation of spectrograms of a particular star is slow, as on the average not more than about 60 to 70 full nights are obtained in the year with the spectrograph, owing to the pressure of other work with the 40-inch equatorial and to weather conditions. The spectrograms of several of the stars have been measured and will be discussed by men recently members of our staff but not now connected with this observatory, especially

by Professor S. A. Mitchell, now director of the McCormick Observatory of the University of Virginia.

4	β *Trianguli*	2^h04^m	*78*	o *Virginis*	13^h29^m
82	δ *Ceti*	2 34	*17*	κ *Boötis*	14 10
48	ν *Eridani*	4 31		*55°1793 Draconis*	15 55
37	φ¹ *Orionis*	5 29	*96*	*Herculis*	17 58
2	*Monocerotis*	5 54	*14*	γ *Lyrae*	18 55
61	μ *Orionis*	5 57	*1*	*Vulpeculae*	19 12
40	*Aurigae*	6 00	*46*	*Sagittarii*	19 16
21	*Lyncis*	7 19	*22*	*Cygni*	19 52
95	*Leonis*	11 51	*65*	τ *Cygni*	21 11
	78°412 Draconis	12 08	*8*	β *Cephei*	21 27
51	θ *Virginis*	13 05	*7*	*Andromedae*	23 08
79	ζ seq. *Ursae Majoris*	13 20	*17*	ι *Andromedae*	23 33

EDWIN B. FROST

Reviews

Die Spektren der Elemente bei normalen Druck. Von Franz Exner und Eduard Haschek. Leipzig: Franz Deuticke, Bd. I, 1911, "Hauptlinien der Elemente und Codex der Starken Linien im Bogen und Funken," pp. 216, M. 18; Bd. II, 1911, "Die Bogenspektren," pp. 347, M. 28; Bd. III, 1912, "Die Funkenspektren," pp. 332, M. 28.

Spectroscopists who used the earlier edition of Exner and Haschek's tables, now ten years old, frequently realized how very unsatisfactory it was to have these tables stop at λ 4600. Such investigators will be glad to welcome the present edition, appearing in three volumes, which carries measures well into the red, to λ 7500, which is made possible by using plates made sensitive to the red by bathing with pinacyanol. In order to have their results quite accordant, the authors repeated their measures for the earlier edition from about λ 4300. In the last ten years there have been new subdivisions of the elements especially in the rare earths. Ytterbium has disappeared as an element and instead we find neoytterbium and lutecium. Holmium has likewise disappeared as an element, but terbium, dysprosium, and neoholmium have been added.

Measures were made on the spectra of both arc and spark at atmospheric pressure from the ultra-violet to the deep red, and in their tables 61,580 lines in the arc spectrum are enumerated, and in the spark 60,252 lines. Photographs were taken by means of a Rowland 4-inch grating of 15 feet radius and 20,000 lines per inch. Exposures were made always in the first order on plates 4×30 cm, and each spectrum was photographed in ten sections. The camera was so arranged that on each plate three exposures were made, the arc spectrum, the spark spectrum, and the comparison spectrum of iron. The latter was placed between the other two and this middle spectrum was so arranged that it slightly overlapped the spectra above and below.

Instead of measuring these plates by the ordinary method, by means of a micrometer microscope, the photographs were projected on a screen. By very ingenious devices, the authors were able, by suitable additions to the lantern and a screen and scale of certain construction,

to project the photographs in such a way that one angstrom unit was equal to one centimeter on the screen. The scale attached to the screen was graduated to millimeters and the positions of the lines were estimated to tenths, so that it was possible to read their wave-lengths directly from the screen to 0.01 angstroms, 250 A. appearing on the screen at once; but of these 100 A. only were measured at the center of the screen.

As a result of their many years of experience with this method of measurement, the authors regard it to be quite equal in accuracy, but decidedly quicker than the actual measurement by means of micrometer. It was possible for them to measure a spectrum of 64 lines in 1^h30^m, a spectrum of 963 lines in 5^h30^m, and a spectrum of 2600 lines in 8^h22^m. As a matter of fact, it would be almost impossible to measure the 120,000 lines enumerated in their table by the well known and generally used method of measuring by micrometer.

Investigators in astrophysics will naturally question the accuracy of this method of measurement. The authors were able to make a great number of comparisons by measuring the same spectrum twice, by investigating the wave-lengths of the impurities which appear in a great number of different spectra, etc., and they find that their average error for 6995 lines is 0.016 A. They made a similar comparison for different authors who have published similar measures and they find the results to be about equal in the two cases.

Those who have occasion to investigate wave-lengths will be interested in the following table, which gives the number of lines measured by them in the 77 elements investigated. These elements are arranged in order of their atomic weights.

One will notice at once that these measures are in some respects sadly lacking: hydrogen, for instance, has but one spark line, and carbon only one line in the arc and 28 in the spark.

These tables of Exner and Haschek cover somewhat the same field as in Kayser's *Handbuch der Spectroscopie*, Vols. **5** and **6**. The difference is that Exner and Haschek give all the lines of all the elements; Kayser tabulates only the stronger lines, from the measures by various authors, but with a critical discussion.

While investigating the spectrum of the chromosphere from the 1905 eclipse, the reviewer had need to find the origin of the lines in the chromosphere and in the sun. Comparisons with Rowland's tables left much to be desired in the way of identifications. Fortunately the present edition of Exner and Haschek appeared before this work was completed. The

Symbol	Atomic Weight	No. Lines		Symbol	Atomic Weight	No. Lines	
		Arc	Spark			Arc	Spark
H.......	1	0	1	*Rh*.....	103	1002	948
Si.......	7	13	12	*Pd*.....	106	268	532
Be.......	9	9	10	*Ag*.....	108	27	380
Bo.......	11	2	3	*Cd*.....	112	38	129
C.......	12	1	28	*In*.....	114	28	30
N.......	14	0	142	*Sn*.....	119	44	103
O.......	14	0	113	*Sb*.....	120	38	200
Fl.......	19	0	69	*Te*.....	127	4	111
Na.......	23	25	13	*I*.....	127	0	172
Mg.......	24	52	58	*Cs*.....	133	14	66
Al.......	27	28	115	*Ba*.....	137	207	148
Si.......	28	40	49	*La*.....	138	512	356
P.......	31	15	85	*Ce*.....	140	2894	1758
S.......	32	0	44	*Pr*.....	140	2490	1732
Cl.......	35	0	101	*Nd*.....	144	2762	2540
K.......	39	18	61	*Sa*.....	150	1679	1085
Ca.......	40	114	84	*Eu*.....	151	857	1508
Sc.......	44	342	204	*Gd*.....	156	1687	1411
Ti.......	48	1132	1705	*Tb*.....	159	2487	1409
V.......	51	1642	2837	*Nh*.....	...	1482	1222
Cr.......	52	1697	1806	*Dy*.....	163	3312	1464
Mn.......	55	865	1216	*Er*.....	166	2321	1785
Fe.......	56	2392	1838	*Tm*.....	171	1007	667
Co.......	59	1830	1360	*Ad*.....	173	905	795
Ni.......	59	976	623	*Cp*.....	174	164	236
Cu.......	64	368	328	*Ta*.....	183	1285	1560
Zn.......	65	35	134	*Wo*.....	184	3254	3912
Ga.......	70	14	14	*Os*.....	191	1340	867
Ge.......	72	27	62	*Ir*.....	193	806	1400
As.......	75	18	69	*Pt*.....	195	401	618
Se.......	79	0	63	*Au*.....	197	35	370
Br.......	80	0	153	*Hg*.....	200	78	99
Rb.......	85	19	62	*Tl*.....	204	22	18
Sr.......	88	146	89	*Pb*.....	207	46	84
S.......	89	684	430	*Bi*.....	209	48	121
Zr.......	91	1070	1529	*Ra*.....	226	50	10
Nb.......	94	1770	2086	*Th*.....	232	2316	2298
Mo.......	96	3390	3248	*U*.....	240	4940	5655
Ru.......	102	1948	1659				

reviewer found their wave-lengths on the whole to be accurate to about 0.03 or 0.04 A. with individual discrepancies of double that amount. He found the wave-lengths in practically all cases thoroughly reliable. He found the spectra almost without impurities, and he wishes hereby to record his deep obligation and gratitude for these tables, without which the identifications could not possibly have been made as complete as they were.

S. A. Mitchell